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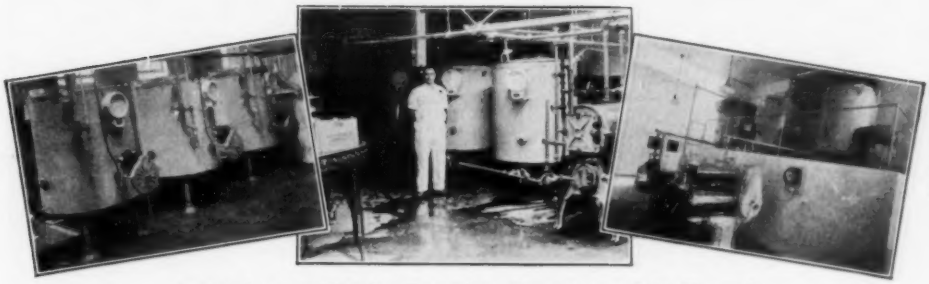

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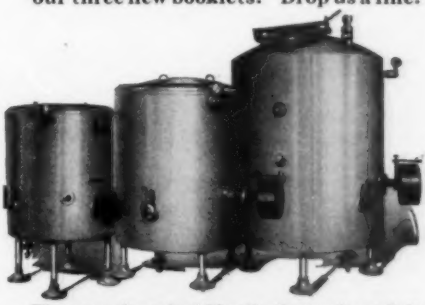

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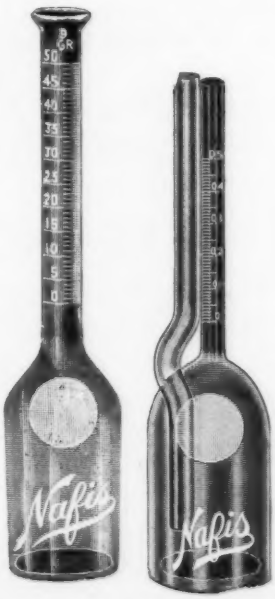

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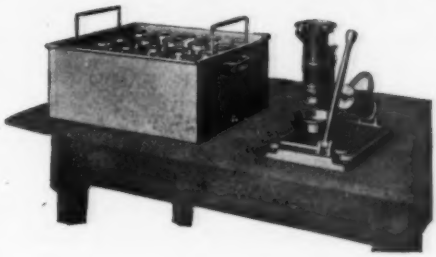

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GASSY FERMENTATIONS IN REHEATED OR PROCESSED CHEESE PRODUCTS CONTAINING PIMENTOS*

W. R. ALBUS

Research Laboratories, Bureau of Dairy Industry, United States Department of Agriculture

AND

S. HENRY AYERS

Research Director, Glass Container Association of America

Manufacturers of cream cheese, loaf cheese, and cheese spreads experience considerable difficulty from gassy fermentations when pimentos are incorporated in these products. The same difficulty is experienced with other food products that contain pimentos. In most cases bacteria are responsible for the fermentations. In unheated products, however, such as cream cheese, the fermentation may be due to the presence of yeasts. This paper deals particularly with gassy fermentations in reheated or processed cheese products.

Reheated or processed cheese products are particularly favorable media for the growth of bacteria. There is present an abundance of easily available protein and inorganic salts. The water which is added to these products in the manufacturing process increases the moisture content beyond that of the cheese from which they are made; in cheese spreads the moisture is often as high as 50 per cent. The salts that are usually added to bring about the necessary homogeneity in the products increase their buffer content accordingly. The incorportation of pimentos supplies a fermentable carbohydrate. The bacteria which have survived the manufacturing process or have found their way into the product from equipment or containers find, therefore, favorable conditions for growth. This is particularly true in the case

* Received for publication December 13, 1927.

of the anaerobic organisms, since the products are packaged while hot and therefore contain very little free oxygen.

Certain anaerobic spore-forming bacteria are usually responsible for the gassy fermentations in reheated cheese products to which pimentos have been added to obtain variety. The source of these bacteria may be the cheese from which the products are made. Spore-forming anaerobes have frequently been isolated from cheese and in the spore state these bacteria survive the temperatures of processing. Because of the destruction by the heating process of practically all other types of organisms in the cheese, germination of the spores and subsequent growth of the anaerobes proceeds with little competition. Certain cocci which are known to survive the heating process multiply quite rapidly in the finished cheese product but these apparently do not interfere with the development of gas-producing bacteria.

A spore-forming anaerobic organism, capable of producing a vigorous gassy fermentation in pasteurized cheese products, has been found in both foreign- and domestic-packed pimentos. This is contrary to the experience of Warren (1) who reported that he found canned pimentos to be sterile. It is therefore of utmost importance that the pimentos be sterilized under pressure before they are incorporated in the food product, in order that inoculation from this source may be prevented. The sterility of the pimentos may easily be determined by adding a small quantity of them to freshly sterilized and cooled milk and incubating it for several days at a temperature of 37° to 40°C.

The containers in which the products are packed may sometimes be the source of gas-producing bacteria, in spite of the fact that they have been passed through a washing process. Contamination from this source can easily be determined by filling some of the containers with freshly sterilized, quickly cooled milk, capping and setting in a warm place to incubate.

Unclean equipment as a source of contamination should be too familiar a subject to warrant discussion in this paper.

It is possible, then, to protect reheated or processed cheese products from contamination with gas-producing bacteria from every source except the cheese itself. Contamination from this

source might also be controlled and the gassy fermentation prevented if it were economically possible to use only the best quality of cheese. Inasmuch as a certain amount of cheese of poor quality is always used, the possible presence of gas-producing bacteria must be accepted. Sterilization of the manufactured products is obviously impossible. It remains, therefore, to render the products less favorable as media for the development of the gas-producing bacteria if the fermentation is to be prevented. This was attempted by removing the fermentable carbohydrate from the pimentos. In the absence of a fermentable sugar a gassy fermentation is not likely to take place. Certain anaerobic gas-producers can utilize lactates with the production of gas; but this rarely occurs unless very young cheeses are used.

Both foreign- and domestic-packed pimentos were used in the experiments carried out. The pimentos were washed in double their weight of tap water three times in thirty minutes. They were then allowed to stand in fresh water for about 18 hours. The pimentos were then rinsed in fresh water, ground and sterilized.

A quantity of plain cheese spread was warmed until it reached a semifluid consistency. It was then divided into two equal portions. To one portion 10 per cent of sterilized washed pimentos was added, and to the other 10 per cent of ground, sterile unwashed pimentos. Both portions were put in small glass jars, capped and left standing in a warm place. Gas developed in the jars of cheese to which the unwashed pimentos had been added, but no gas was evident in the product which contained the washed pimentos.

This experiment has been repeated a number of times, with different batches of cheese. The quantity of the pimentos used has varied from 4 to 10 per cent. In every case in which gas developed in the cheese containing unwashed pimentos, the same cheese containing washed pimentos was free from gas.

It is true that some of the flavor and color of the pimentos are lost in the washing process. It is believed, however, that the washing was excessive and can be considerably lessened, in which case the flavor and color of the pimentos would be little affected.

This method has not been tried out on a factory scale; but the results obtained in laboratory experiments have been so favorable that successful application to factory practice is believed to be assured.

Although the studies reported have been confined to reheated cheese products, the findings are applicable to all food products in which pimentos are incorporated which are subject to a gassy fermentation.

SUMMARY

1. It has been found that washing the pimentos to remove the fermentable sugar they contain prevents the development of a gassy fermentation in reheated or processed cheese products in which pimentos have been incorporated.

REFERENCE

(1) WARREN, D. H.: Jour. Dairy Sci., ix, (1926).

THE VALUE OF SILAGE IN THE EXPERIMENTAL RATION*

H. T. CONVERSE

Research Laboratories of the Bureau of Dairy Industry, United States Department of Agriculture

The best method of attack for many nutritional studies of dairy cows is to find a ration that will allow the cows to give as nearly as possible their maximum milk yield year after year with no interruption in reproduction. Such a ration when found should be fed for one lactation period, and the data obtained during this period would become the base-line measure of the producing ability of each cow to be studied. Later the various nutritional factors should be tried out separately and the results measured quantitatively, using the results of the base-line lactation as a standard. For obvious reasons such a basal ration should be as simple as possible.

Nutritional studies of this nature are being made at the Bureau of Dairy Industry experiment station at Beltsville, Maryland. The basal ration is changed from time to time when trial proves certain constituents unsatisfactory. Thus the ration may be simplified or a certain constituent may be replaced by one which appears to be better.

The question as to whether or not silage should be used in such a ration is of considerable importance. Investigators who conduct comparative feeding trials where the balance of nutrients is rather carefully made, as well as those who carry on complete balance experiments, know how difficult it is to obtain accurate data when silage is used. Silage is greatly variable in nutrient content in different parts of the same silo, but it is even more so from year to year. The presence of cobs makes the taking of small accurate samples extremely difficult. Thus the feeding of silage in the balance-experiment ration greatly increases the

* Received for publication January 7, 1928.

labor involved and decreases the accuracy of the results. In the long-time feeding trials, involving ration comparisons, the variability of the quality of the silage when fed in large amounts may be great enough to make the results very inaccurate.

In April, 1922, many cows in the herd at Beltsville showed marked signs of digestive disturbance, such as off feed, scouring, and sudden drop in milk yield, which were due in all probability to some peculiar mold in the silage. When the silage feeding was discontinued, recovery was almost immediate. To forestall a repetition of these difficulties very few cows in the nutrition herd have received silage since that time. The basal ration has been simplified by discontinuing silage feed, and the results show that production has not been reduced.

In the latter part of 1925 it was decided to carry out some carefully controlled feeding trials to decide conclusively whether the basal ration of alfalfa hay and a grain mixture was producing as much milk as would a similar ration which included silage. These trials seemed necessary, since silage feeding had been discontinued in spite of the traditional teaching that some succulence, that is, feed retaining its plant juices, should be included in the ration.

SOME RESULTS AT OTHER STATIONS

Investigations concerning the value of silage in the ration fall roughly into the following classes: (*a*) early work carried on about 1890, in which corn-silage feeding was largely compared with corn-fodder feeding; and (*b*) later work with more adequate rations in which results of silage feeding were usually compared by substituting silage for a portion of the legume hay of the non-silage ration.

Even in the early work carried out at the Wisconsin (10, 15) and Vermont (7) Stations in which the cows were frequently fed as much silage and corn fodder as they would eat, the results varied from those slightly in favor of corn-fodder feeding to those considerably in favor of corn-silage feeding. Frequently, however, the consumption of silage, because of its greater palatibility, was considerably larger than that of corn fodder. In two

cases at the Vermont (11) and Maine (2) Stations where silage was compared with mixed or timothy hay the silage ration produced more milk, though in one experiment the difference in nutrients consumed nearly accounted for the difference in yield. In most of these experiments, as well as in those of the second group, the periods were short, varying from twenty to thirty days.

The more recent trials are mentioned singly but briefly. Those in favor of the silage ration are stated first. At the Ohio Station (13) five cows in each of two groups seemingly ate about the Savage requirements and the silage group produced more milk, but as the groups were not reversed the evidence is not conclusive. Cows fed considerably over requirements for two brief periods by reversal at the Montana Station (5) produced about 2 per cent more milk on the silage ration. The production of twelve cows fed oat and pea silage versus mixed hay for twenty-one day periods by reversal at the Pennsylvania Station (3) showed a very large difference in favor of silage, though on calculation it appeared that both rations were about 20 per cent short of the Savage requirements. The silage ration in the experiments at the Utah Station (4) gave less than 2 per cent increase in production though this ration contained about 1 per cent more nutrients. The Purdue University (8) results showed about 10 per cent more production on the silage ration, which, however, contained about 5 per cent more nutrients.

The Nebraska Station (12) reports about 2 per cent greater production on the non-silage ration, but no substantiating data were given. At the Arizona Station (14) seven cows divided into two groups of four and three were fed, by reversal, a ration of 30 pounds of alfalfa hay and a ration of 20 pounds of the hay and 35 pounds of silage, no grain being fed. The hay ration produced about 2 per cent more milk, though the silage ration must have contained at least 6 per cent more nutrients. Sixteen cows were fed for four periods at the New Mexico Station (9). One ration contained 35 pounds of alfalfa and 6 pounds of grain, and the other contained 28 pounds of silage, 22.7 pounds of alfalfa, and 6 pounds of grain. The cows receiving the nonsilage ration produced about 6 per cent more milk but this ration contained about 6 per cent more nutrients.

In the Montana and Pennsylvania trials and especially in the Purdue experiment, considerable credit was given to silage in maintaining or increasing body weight. During the brief periods of some of the experiments gains as great as some of those mentioned could hardly be actual tissue gains but must have been due at least partly to intestinal fill. This tendency of silage to mask the actual body gain by increasing the intestinal fill was pointed out at the Wisconsin Station in 1888 and 1889 (10, p. 36; 15, p. 78). The differences in body weight attributed to fill alone ranged from 16 to 45 pounds. Reference was also made to the effect of silage on body weight by an English writer (1) who in 1888 stated that a silage-fed steer was found to have a dressing out percentage of only 55 in contrast to a nonsilage fed heifer with a dressing out percentage of 71.

THE EXPERIMENT

Nine cows were fed alternately a ration of alfalfa hay and grain and a ration of alfalfa hay, grain, and corn silage. For one cow each period of feeding was three calendar months. For all the other cows each period was two calendar months. Each cow was on the experiment from six to ten months.

It was planned that the cows at all times should get 110 per cent of the total digestible nutrients called for by the Savage feeding standard. The hay fed varied from a fairly good grade to a very good grade of alfalfa. The hay and grain ration, therefore, included more digestible protein than the ration containing silage. Two grain mixtures were used. The first five cows,—which were started on the experiment in the spring of 1926,—received a mixture containing 2 parts, by weight, wheat bran; 2 parts yellow corn meal; 1 part linseed-oil meal; and 1 per cent salt. The other four cows,—which were started late in 1926,—were fed a mixture, by weight, of 4 parts corn meal, 3 parts wheat bran, 2 parts soy-bean meal, 1 part linseed-oil meal, and 1 per cent salt. Hay and grain were fed in as nearly as possible equal amounts in all the periods, both being reduced in quantity when silage was fed. The first five cows—four Jerseys and a grade Guernsey—were offered 8 kgm. of silage per day; whereas the

other four cows, which were Holsteins, were given 14 kgm. per day.

The milk was weighed regularly and the butterfat was determined by two-day samples taken the fifth, fifteenth, and twenty-fifth of each month. The feeds were not analyzed, but the total digestible nutrient content of the rations was considered the same as the average figures in the seventeenth edition of "Feeds and Feeding" by Henry and Morrison.

THE RESULTS

Table 1 gives the data concerning the cows used and the average daily production of milk and butterfat and feed nutrients consumed in each feeding period. The number of periods for each cow varied from three to five. In summarizing the results, when a cow was fed for three periods, the first and third periods were averaged and compared with the second. When a cow was fed for more than three periods, the second and fourth periods were averaged and compared with the third, etc. Whenever one cow was used in more than one comparison, these comparisons were averaged before being averaged for a group.

Table 2 gives the summary of the results. Cows on the non-silage ration produced an average of 2.8 per cent more milk and 4.2 per cent more butterfat than on the silage ration. Only one cow produced more milk on the silage ration. This cow (N201) decreased in milk yield very rapidly during the last month of the last nonsilage period because of her late stage of pregnancy, thus giving to the silage period the advantage found.

In another paper (6) attention was called to the fact that sometimes the comparative decline in production in the different period is a better index of results than a comparison of the period totals. Figure 1 gives the average daily production by ten-day periods for seven of the nine cows, grouped according to the length of time on the experiment and the order of periods. To save space only those cows were used which could be put into groups. Because of advanced pregnancy the third-period declines of cows N201 and N204, and cows N205 and N206 are not shown.

The declines do not show the marked difference between the

TABLE 1

Detailed information about the cows used, together with the average daily yield of milk and butterfat and the daily consumption of feed nutrients

COW NUMBER	BREED*	MONTHS ON TEST	AGE	AVERAGE WEIGHT	FEEDING PERIOD	MILK PRODUCTION	BUTTERFAT PRODUCTION	NUTRIENTS RECEIVED	
								Digestible protein	Total digestible nutrients
			years	*kgm.*		*kgm.*	*kgm.*	*kgm.*	*kgm.*
600	J	March–April	2½	454	No silage	6.1	0.38	1.37	7.0
600		May–June		465	Silage	5.8	0.38	1.22	7.2
600		July–August		467	No silage	5.2	0.34	1.33	6.9
600		September–October		469	Silage	4.4	0.30	0.90	5.5
600		November–December		478	No silage	3.3	0.24	1.13	5.9
605	J	March–April	2½	388	No silage	7.5	0.38	1.36	7.0
605		May–June		407	Silage	6.9	0.40	1.24	7.0
605		July–August		400	No silage	6.7	0.37	1.26	6.5
605		September–October		423	Silage	5.2	0.32	1.13	6.5
458	J	April–May	4½	411	Silage	10.1	0.62	1.36	7.3
458		June–July		402	No silage	9.5	0.60	1.46	7.5
458		August–September		404	Silage	8.5	0.55	1.25	7.3
458		October–November		412	No silage	7.5	0.51	1.21	6.2
499	J	January–February	2½	401	No silage	7.3	0.47	1.35	7.0
499		March–April		415	Silage	7.4	0.46	1.22	7.1
499		May–June		420	No silage	7.8	0.49	1.27	6.6
499		July–August		416	Silage	7.2	0.44	1.16	6.5
99	GG	April–May–June	5½	429	No silage	10.9	0.42	1.33	6.9
99		July–August–September		420	Silage	8.5	0.34	1.18	6.8
99		October–November–December		466	No silage	6.7	0.27	1.38	7.1
N201	H	November–December	7+	606	No silage	16.2	0.57	2.19	10.1
N201		January–February		624	Silage	15.1	0.54	1.81	9.8
N201		March–April		632	No silage	10.4	0.38	2.00	9.2
N204	H	November–December	5+	587	No silage	10.2	0.36	1.81	8.3
N204		January–February		613	Silage	8.3	0.28	1.29	7.7
N204		March–April		607	No silage	7.4	0.25	1.60	7.4
N205	H	December–January	5+	493	Silage	19.2	0.72	2.11	11.4
N205		February–March		502	No silage	20.2	0.75	2.56	11.8
N205		April–May		519	Silage	17.3	0.66	1.87	10.1
N206	H	December–January	5+	593	Silage	19.5	0.67	2.19	11.6
N206		February–March		599	No silage	18.3	0.70	2.53	11.6
N206		April–May		633	Silage	14.8	0.56	1.93	10.5

*J, Jersey; GG, Grade Guernsey; H, Holstein.

silage and nonsilage rations that was found in the experiments carried out at Purdue (8). On the contrary, the production curves confirm the figures in table 2 in showing that there was

TABLE 2

Summary of results

The figures represent average daily milk yields, etc.

	COW NUMBER	AVERAGE MILK YIELD	AVERAGE BUTTER-FAT YIELD	NUTRIENTS REQUIRED		NUTRIENTS FED		PLANE OF NUTRITION*
				Digestible protein	Total digestible nutrients	Digestible protein	Total digestible nutrients	
		kgm.	*kgm.*	*kgm.*	*kgm.*	*kgm.*	*kgm.*	*per cent*
No silage	600	5.1	0.33	0.76	6.2	1.30	6.8	109.7
	605	6.9	0.38	0.76	6.3	1.29	6.7	106.3
	458	9.0	0.58	1.06	7.7	1.40	7.2	93.5
	499	7.7	0.49	0.94	7.1	1.29	6.7	94.4
	99	8.8	0.35	0.89	6.7	1.36	7.0	104.5
	N201	13.3	0.48	1.21	8.7	2.10	9.7	111.5
	N204	8.8	0.31	0.92	7.1	1.71	7.9	111.3
	N205	20.2	0.75	1.60	10.5	2.56	11.8	112.4
	N206	18.3	0.70	1.55	10.5	2.53	11.6	110.5
	Average	10.9	0.49	1.08	7.9	1.73	8.4	106.3
Silage	600	5.1	0.34	0.77	6.2	1.06	6.4	103.2
	605	6.5	0.38	0.82	6.3	1.22	6.9	109.5
	458	8.9	0.57	1.05	7.6	1.28	7.3	96.1
	499	7.4	0.46	0.91	6.9	1.21	7.0	101.4
	99	8.5	0.34	0.85	6.4	1.18	6.8	106.3
	N201	15.1	0.54	1.32	9.3	1.81	9.8	105.4
	N204	8.3	0.28	0.89	7.0	1.29	7.7	111.6
	N205	18.3	0.69	1.50	10.0	1.99	10.8	108.0
	N206	17.2	0.62	1.44	10.0	2.06	11.1	111.0
	Average	10.6	0.47	1.06	7.7	1.46	8.2	106.5

* Plane of nutrition is the total digestible nutrients eaten by the cow expressed in percentage of the requirement of the Savage standard.

no appreciable difference in the two rations used. Under the conditions of the experiment, therefore, silage was not effective in increasing milk production.

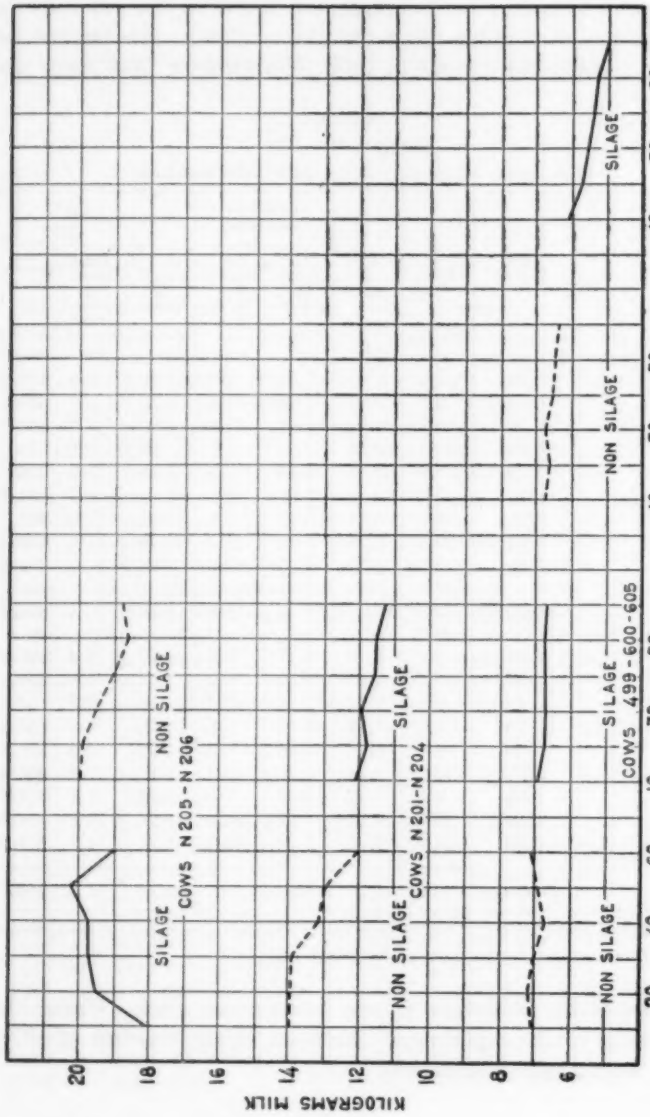

FIG. 1. DECLINE IN MILK YIELD DURING PERIODS WITH AND WITHOUT SILAGE

The cows were supposed to consume 110 per cent of the total digestible nutrients called for by the Savage feeding standard. Although five of the cows did not consume this quantity of feed, yet the nutrients consumed under the two conditions of the study were quite comparable. The figures indicate that these five cows consumed on the average exactly the same quantity of nutrients whether silage was included in the ration or not. In the case of two or three of these cows, however, the addition of silage did seem to increase very slightly the quantity of nutrients they would consume.

CONCLUSIONS

Under the conditions of this experiment, whether silage was fed or not made practically no difference in the milk and butterfat yields. It should be pointed out, however, that in the experiment very moderate quantities of silage were added to a good ration, which, even after this addition, still contained a liberal quantity of good legume hay. The results throw no light on the question as to what would happen if, for instance, the hay were largely or entirely replaced by silage. Furthermore, no attempt was made in the study to disprove the fact that silage is a very economical and useful feed in the practical dairy ration or that an otherwise poor ration may be enhanced in value by the addition of silage.

From the results of the experiments, however, it seems that the factor of silage succulence does not increase the value of a ration containing an ample quantity of good alfalfa hay and a satisfactory grain mixture. Thus for experimental purposes, it seems justifiable to simplify the basal ration by leaving out the silage.

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PHYSICAL FACTORS INFLUENCING THE FORMATION AND FAT CONTENT OF GRAVITY CREAM*

H. C. TROY AND PAUL FRANCIS SHARP

From the Chemical Laboratory of the Department of Dairy Industry, Cornell University, Ithaca, New York

INTRODUCTION

The rate of creaming of milk, the depth of the cream layer, and the fat content of the cream and skim milk in gravity creaming have been the subjects for a large number of investigations. It has been shown that various treatments markedly affect the creaming of milk and since many of these treatments also produced other accompanying changes in the milk the conclusion, frequently, has been drawn that a causal relation existed between the creaming of milk and some of the accompanying phenomenon, when actually this was not the case.

Arnold (1) believed that as the milk cooled rapidly the fat did not cool as fast as the plasma, and that therefore cooling produced a great difference in density and caused the cream to rise.

Babcock (2) was the first to call attention to the clumped condition of the fat globules in normal raw milk but he then concluded that clumping tended to prevent cream from rising. Woll, Babcock and Russell (40) and Hammer (15) however associated the clumping of fat globules with creaming. The clumping of fat globules as it influences creaming was specifically studied by Rahn (28) van Dam and Sirks (33) Hekma and Sirks (19) Sirks (31) Brouwer (6) and Hekma (18) who came to the conclusion that normal gravity cream was obtained only when the fat globules were clumped. On the other hand Palmer and Anderson (26) and Palmer, Hening and Anderson (27) have presented the results of experiments which they interpret as

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evidence against the major importance of the clumping of the fat globules as an explanation of creaming. They, however, offer no alternate explanation of the mechanism of creaming. Fleischmann (14) and Bancroft (5) have expressed the view that the larger globules overtake the smaller globules and that they then rise together exerting as Bancroft expresses it, a filtering action.

A study of the gravity creaming of milk has led us to the the conclusion that the clumping of the fat globules plays the major rôle in explaining the creaming phenomenon. Some of our evidence for this conclusion is presented in this paper.

RATE OF RISE OF SINGLE FAT GLOBULES

Equations for the rise of fat in milk have been given by Fleischmann (14) and Richmond (29). Both of their equations contain arbitrary constants. In 1847 Stokes developed the equation for the rate of movement of small spheres at uniform velocity in a viscous medium. Since this equation has been found to hold for so many systems, it should be applicable for calculating the rate of rise of fat globules in milk. Svedberg and Estrup (32) used Stokes equation to determine the size and distribution of fat globules in milk, but some error in their calculations leads to abnormally large sizes for the fat globules. van der Burg (35) called attention to the fact that the individual globules of milk should rise according to Stokes law and Rahn (28) and van Dam and Sirks (33) have presented experimental evidence to show that they actually do.

Stokes equation is as follows:

$$V = \frac{2\, r^2\, (d_s - d_f)\, g}{9\, \eta} \qquad (1)$$

Where V is the velocity of rise in centimeters per second, r is the radius of the fat globule, d_s and d_f are the density of the skim milk and the fat respectively, g is the gravitational constant 980 dynes, and η is the viscosity of the skim milk.

The way in which the temperature affects the rate of rise of the individual fat globules of various sizes can be best appreciated by giving the results of calculations using Stokes equation. In

order to calculate the rate of rise of the fat globules it is necessary to know the density of the fat and the skim milk and the viscosity of the skim milk. The viscosity, expressed in poises, and density of the skim milk as taken from the work of Whitaker, Sherman, and Sharp (37) for four temperatures are given in table 1, together with the density of solid milk fat as determined at the same temperatures.

Table 1, indicates that according to Stokes law the individual fat globules should rise faster at the warmer temperatures for two reasons, first, because of the decrease in viscosity, and second, because the action of the force of gravity is greater due to the greater spread between the density of the fat and the skim milk. In addition the fat globules would be slightly larger at the higher

TABLE 1

Density of skim milk and milk fat and viscosity of skim milk at various temperatures

	TEMPERATURE			
	5°C.	15°C.	24°C.	25°C.
Density of skim milk	1.0365	1.0348	1.0324	1.0322
Density of fat	0.9612	0.9421	0.9227	0.9208
Difference	0.0753	0.0927	0.1097	0.1114
Viscosity of skim milk	0.0296	0.0210	0.0158	0.0154

temperatures due to expansion of the fat. The way in which the constants of the milk affect the rate of rise of the fat globules of different sizes can be understood best by calculating the rate of rise at different temperatures. The results of such calculations are given in table 2.

If we consider that the average diameter of the fat globules in milk is 4μ, it would take 276 hours for the average fat globule to rise from the bottom to the top of a quart milk bottle at 5°C., and 97 hours for it to rise at 25°C. These calculations indicate that faster creaming would occur at 25°C. than at 5°C. while common experience indicates that creaming should be carried out at near the lower temperature. These calculations show that the fat in gravity creaming does not rise as individual globules,

provided that Stokes law holds for the rise of the individual fat globules of milk.

Rahn (28) measured the rate of rise microscopically by two methods. First, by following the rise in a chamber on a slide by keeping the globule in focus and reading the vernier on the microscope to determine the distance traversed by the fat globule, and second, measuring the rate of rise in a slide similar to a blood counting chamber with the stage in a vertical and the tube of the

TABLE 2

Rate of rise at various temperatures of individual fat globules, and the time required for such globules to rise from the bottom to the top of a quart milk bottle (220 mm.), as calculated by Stokes' equation

DIAMETER OF FAT GLOBULES	TEMPERATURE					
	5°C.		15°C.		25°C.	
	Rate of rise per hour	Time to cream in milk bottle	Rate of rise per hour	Time to cream in milk bottle	Rate of rise per hour	Time to cream in milk bottle
μ	mm.	hours	mm.	hours	mm.	hours
1	0.0498	4,417	0.0881	2,497	0.142	1,550
2	0.1994	1,103	0.352	625	0.567	388
3	0.449	490	0.792	278	1.28	172
4	0.798	276	1.409	156	2.27	97
5	1.25	176.	2.201	100	3.54	62
6	1.79	123	3.17	69	5.10	43
8	3.19	69	5.64	39	9.07	24
10	4.99	44	8.81	25	14.2	15.5
14	9.77	22.5	17.26	12.7	27.8	8.0
16	12.76	17.2	22.54	9.8	36.3	6.1
20	19.94	11.0	35.22	6.2	36.7	3.9

microscope in a horizontal position. The time was determined with a stop watch. The results which he obtained by these two methods were in essential agreement, except that the larger fat globules rose more slowly by the second method than they did by the first. The walls of the chamber used in his second method were so close together that they probably slowed down the movement of the fat globules. This effect would naturally become more pronounced the larger the fat globules. van Dam

and Sirks (33) measured the rate of rise of a number of fat globules 3.3μ in diameter finding 1.8 mm. per hour. They calculated the rate according to Stokes equation to be 1.4 mm. per hour.

We have determined how accurately the calculated rate of rise by Stokes' law agrees with the experimentally determined rate. Since temperature so markedly affects the density and viscosity values, it is necessary to make the experimental determinations on the rate of rise at a known temperature. An insulated room was available which did not change rapidly in temperature. Therefore the experimental rate of rise was determined at the temperature of this room. The average temperature was near 24°C.; the deviation was usually less than one-half although occasionally it was as much as 1½ degrees either above or below this temperature.

A wide microscopic slide was used which had three trenches cut lengthwise in the slide. These trenches were 5 mm. wide, 0.5 mm. deep and 70 mm. long. A cover glass large enough to cover all three trenches was sealed to the slide with an appropriate mixture of paraffin and paraffin oil. Samples of skim milk or skim milk to which a drop of whole milk had been added were drawn into the trenches and the ends were sealed by means of paraffin. The microscope was tilted and the slide mounted in a perpendicular position on a mechanical stage. The rate of rise was measured by means of a stop watch by timing the passage of the globules through distances as indicated on an eye piece micrometer. A globule rising in the center of the chamber was selected for measurement in order to minimize the retarding effect of the walls. The size of the globules was estimated at the same time. It was not possible to determine the size of the globules with any considerable accuracy, because they were moving, and the best that could be done was to estimate their size to within a few tenths of a μ. Fat globules of the large sizes were obtained by mixing heated cream with skim milk. A great deal of difficulty was encountered with convection currents. It was necessary to place the adjusted microscope and preparation in a box with only the eye piece protruding. This box was kept in the insulated room and the preparation was given several

TABLE 3

Rate of rise of individual fat globules in milk at 24°C., as calculated by Stokes' equation and as determined experimentally

DIAMETER OF FAT GLOBULES	RATE OF RISE PER HOUR		AVERAGE DEVIATION FROM THE MEAN EXPERIMENTAL VALUE	NUMBER OF OBSERVATIONS
	Calculated	Experimental average		
μ	mm.	mm.		
1.8	0.44	0.55	0.03	6
2.0	0.54	0.67		1
2.25	0.70	0.85	0.15	19
2.40	0.78	0.97	0.39	4
2.52	0.86	1.05	0.07	2
2.70	0.99	1.13	0.15	34
3.20	1.38	1.26	0.17	16
3.60	1.76	2.04	0.80	21
4.50	2.74	2.70	0.33	8
4.95	3.32	3.52	0.28	2
5.40	4.0	3.9	0.6	10
5.75	4.5	5.1		1
6.30	5.3	4.4	1.0	5
6.8	6.3	5.5	1.1	3
7.2	7.0	6.6	1.4	23
7.56	7.8	8.3		1
8.2	9.1	9.7	1.0	5
8.5	9.8	11.3	0.7	3
9.9	13.3	14.7		1
10.8	15.9	19.3	1.9	18
12.6	21.6	27.6	3.1	14
14.4	28.3	29.8	1.9	11
16.2	35.8	38.8	2.9	5
18.0	44.1	41.1	5.0	6
19.8	53.3	49.7	0.7	2
21.6	63.7	66.0	11.4	3
25.2	85.8	85		1
27.0	99.5	124	5.0	4
30.6	127	119		1
32.4	143	161		1
34.2	160	143		1
36	177	174	20	3
37.8	195	185		1
39.6	214	215		1
41	229	242	29.0	2

hours time to come to temperature equilibrium. The artificial light used was passed through water. The increase in temperature caused by the light and by the presence of the observer in the room would start convection currents in the preparation in less than an hour, so that no more readings were taken when convection currents were noted. These convection currents could be recognized by the behavior of the smallest globules.

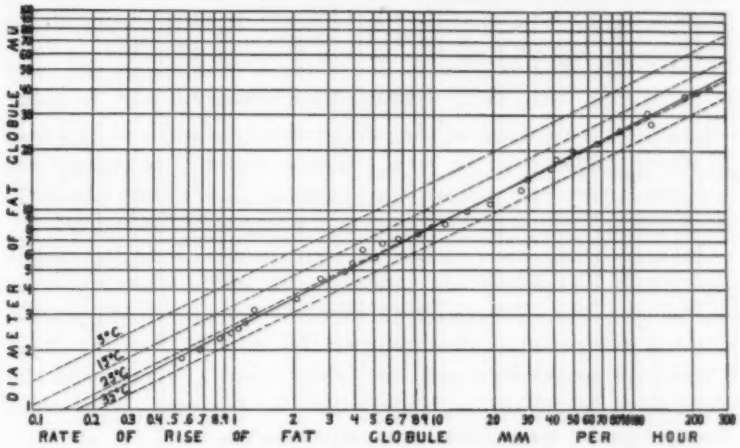

FIG. 1. LOGARITHMIC PLOTTING OF THE RATE OF RISE OF INDIVIDUAL FAT GLOBULES OF VARIOUS SIZES

The broken lines express the rate of rise as calculated from Stokes equation for the different temperatures. The circles represent the experimental values obtained at 24°C. The solid line represents the best line which can be drawn through the experimental points.

Table 3 contains the experimental data obtained on the rate of rise of individual fat globules in skim milk. This table includes only the data obtained after the technique was perfected. When the logarithms of the rate of rise, as calculated by Stokes' equation, are plotted against the logarithms of the diameter of the fat globules, the results fall on a straight line. The calculated rates of rise at 5°, 15°, 25°, and 35°C. are represented in figure 1 by the broken lines and the experimental data of table 3 by the

circles. The agreement between the calculated and experimental rates of rise is excellent considering the experimental difficulties involved.

Since the logarithmic plotting of this data approximates a straight line, the equation for a straight line was fitted to the data.

$$\log y = A + B \log x \tag{2}$$

and the constants A and B were calculated by the method of least squares. The equation for the best line which can be drawn to represent the experimental data as given in table 3 is

$$\log y = 0.4059 + (0.5140) \log x \tag{3}$$

where y is the diameter of the fat globules in μ, and x is their rate of rise in millimeters per hour. The constant B represents the tangent of the angle or the slope of the line, and should be 0.5000 since the velocity is proportional to the square of the radius.

In calculating the rate of rise from Stokes' equation, slight errors may be made in the densities used, in the viscosity, or in the temperature. These will all affect the constant A of equation (2), but will have no influence upon the constant B or the slope. The experimental slope as given by equation (3) agrees with the slope given by Stokes' equation within 2.8 per cent. The solid line in figure 1 was plotted from equation (3).

In determining the rate of rise experimentally the greatest errors occurred in measuring the rate of rise and size of the smallest fat globules. Convection currents produced proportionately, a greater effect on the rising of the small fat globules than on the large ones. The movement of the smallest globules was so slow that there was probably a tendency to select the globules which were rising aided by very slight convection currents. This error would tend to increase the slope of the line. An error of 0.2μ in estimating the size of the smallest globules would entirely account for the difference between the experimental and calculated rate of rise.

If the first five points in table 3 and figure 1 are omitted, and the linear equation is calculated for the remaining 30 points by the method of least squares, the following result is obtained:

$$\log y = 0.4273 + (0.4995) \log x \tag{4}$$

The slope of the line in equation (4) is within 0.1 per cent of the slope calculated by Stokes' equation.

In order to show more clearly the relation between the experimental and calculated rates of rise, table 4 was constructed. The rates of rise at 24° and 25°C. were calculated using Stokes' equation; also the experimental rates of rise were calculated by equations (3) and (4). It will be noted that the rates of rise given by equation (4) fall between the calculated rates for 24° and 25°C. Since 1°C. makes a difference of about 4 per cent in the rate of rise, the agreement between the calculated and experimental rates of rise is exceptionally good. This good agreement is

TABLE 4

Rate of rise of fat globules in millimeters per hour, as calculated by Stokes' equation and as determined experimentally

SIZE OF FAT GLOBULE	CALCULATED BY STOKES' EQUATION		EXPERIMENTAL CALCULATED FROM	
	24°C.	25°C.	Equation (4)	Equation (3)
μ				
1	0.136	0.142	0.140	0.163
2	0.544	0.567	0.560	0.627
4	2.18	2.27	2.24	2.41
6	4.90	5.10	5.04	5.31
10	13.6	14.2	14.02	14.4

probably better than the experimental errors justify and was obtained only because of the large number of determinations made by very careful experimentation, and only after a number of experimental difficulties were overcome. It may be concluded that Stokes' equation expresses quite accurately the rate of rise of individual fat globules in milk, when the globules are far enough apart so they exert no effect on each other. Rahn (28) measured the rate of rise of individual fat globules in whole milk. Since his results are in essential agreement with those reported here, it is probable that the individual fat globules in whole milk exert no pronounced influence upon the rate of rise of each other.

RATE OF RISE OF FAT CLUMPS

Since the individual fat globules rise too slowly to account for gravity creaming some other explanation must be sought. Rahn (28), van Dam and Sirks (33) and van der Burg (36) have considered that clumping of the fat globules was necessary in order that the gravity cream might rise in a reasonable time. It has long been known that the fat globules in normal raw milk are present mainly in the form of clumps or clusters, and not as separate fat globules. These clusters should rise much faster than the individual globules, because according to Stokes' equation the rate of rise depends on the square of the radius; thus the rate increases very rapidly with size. On the other hand, the clusters would contain plasma in the spaces between the individual globules, and consequently the rate of rise of a cluster would not be as rapid as that of a fat globule of equal size. It is possible for uniform spheres under the condition of maximum packing to occupy 74.04 per cent of a volume without deformation. This condition of packing is independent of the diameter of the spheres. It is not known exactly what part of the volume of a cluster is occupied by fat and what part by skim milk. The ratio of volume of fat to volume of plasma in the cluster varies with the conditions. Assuming that the clusters are spherical, calculations using Stokes' equation were made on the basis of clusters containing 75, 50, and 25 per cent fat. The results are presented in table 5, and give some idea of the effect of the various factors on the rate of rise of clusters.

It will be observed that some of the calculated rates of rise as given in table 5, are fast enough to account for normal creaming, provided clusters of sufficient size are found in milk. The size and rates of rise of a number of clusters found in milk were measured. The samples used for these determinations were prepared by adding a drop or two of cream or whole milk to skim milk. The clusters were of various shapes and sizes. Some of the clusters were apparently spherical, the fat globules being closely packed in the cluster, while others were of irregular shape with projections and frequently they had holes in them. After

TABLE 5

Rate of rise of fat clusters at various temperatures, and the time required for such clusters to rise from the bottom to the top of a quart milk bottle (220 mm.), as calculated by Stokes' equation, assuming that the clusters are spherical and that the fat occupies 25, 50, and 75 per cent of the volume of the cluster

Diameter of clusters	75 per cent fat		50 per cent fat		25 per cent fat	
	Rise per hour	Time to cream in milk bottle	Rise per hour	Time to cream in milk bottle	Rise per hour	Time to cream in milk bottle
			5°C.			
μ	mm.	hours	mm.	hours	mm.	hours
10	3.75	58.7	2.50	88.0	1.25	176.0
20	15.0	14.7	9.98	22.0	4.99	44.0
30	33.7	6.5	22.44	9.8	11.22	19.6
40	59.8	3.68	39.8	5.5	19.9	11.0
60	135	1.63	89.8	2.5	44.9	4.9
80	239	0.92	159.6	1.38	79.8	2.76
100	375	0.59	250	0.88	125	1.76
150	841	0.26	560	0.39	280	0.78
200	1,500	0.15	998	0.22	499	0.44
			15°C.			
10	6.49	33.9	4.31	51.0	2.16	102
20	25.9	8.5	17.2	12.8	8.6	25.6
30	58.4	3.8	39.0	5.65	19.5	11.3
40	104	2.12	69.2	3.17	34.6	6.34
60	234	0.94	155	1.42	77.5	2.84
80	415	0.53	277	0.79	139	1.58
100	649	0.34	431	0.51	216	1.02
150	1,360	0.16	973	0.23	487	0.45
200	2,590	0.09	1,720	0.13	860	0.26
			25°C.			
10	10.6	21.0	7.09	30.9	3.55	61.9
20	42.5	5.25	28.4	7.75	14.2	15.5
30	95.7	2.33	63.8	3.45	31.9	6.90
40	170	1.31	113.4	1.94	56.7	3.88
60	383	0.581	255	0.86	128	1.72
80	681	0.328	454	0.49	227	0.969
100	1,060	0.210	709	0.31	355	0.620
150	2,390	0.093	1,600	0.14	800	0.275
200	4,250	0.052	2,840	0.08	1,420	0.155

considerable difficulty a technique was developed for measuring the rate of rise of the clusters. All of these determinations were made in trenches 5 mm. wide, 1 mm. deep and 70 mm. long. Here again care was taken to avoid as much as possible the error caused by convection currents. Both the horizontal and vertical diam-

TABLE 6

Rate of rise of fat clusters in milk at 25°C.

DIAMETER OF CLUSTER	AVERAGE RATE OF RISE PER HOUR	MEAN DEVIATION	NUMBER OF OBSERVATIONS	DIAMETER OF CLUSTER	AVERAGE RATE OF RISE PER HOUR	MEAN DEVIATION	NUMBER OF OBSERVATIONS
μ	mm.			μ	mm.		
9–10	8.0	0.1	3	75–80	323	11	11
10–11	9.9	0.6	2	80–85	327	102	3
11–12	11.5	2.7	4	85–90	419	102	9
13–14	14.9	3.1	5	90–95	462	104	2
14–15	15.9	1.6	4	95–100	665	128	11
15–16	17.6	0.9	2	100–110	720	240	2
16–17	19.3	2.6	6	110–120	791	152	9
17–18	28.1	13.4	3	120–130	884	303	5
19–20	22.3	2.0	4	130–140	1,238	202	5
20–22	26.0	4.3	3	140–150	981	171	8
22–24	36.0	11.4	5	150–160	1,331	145	7
24–26	30.1	3.6	4	170–180	1,255	200	7
26–28	49.7	17.9	11	190–200	1,302	198	3
28–30	35.5	2.6	9	200–220	1,228	385	6
30–32	64.0	20	9	220–240	2,082	317	6
34–36	102	22	13	240–260	2,880	0	2
38–40	141	15	14	260–280	1,847	210	2
42.5–45	133	27	7	280–300	1,893	658	3
47.5–50	155	33	8	300–320	1,454	146	2
50–52.5	208	15	4	320–340	3,200	1,600	2
55–57.5	211	23	6	380–400	2,445	289	3
57.5–60	241	60	8	425–450	5,200	1,333	3
60–65	263	46	16	475–500	3,840	960	2
65–70	265	28	4	700–750	5,800	2,000	2
70–75	341	100	17	750–800	5,600	1,067	3

eters of the clumps were measured, and the average taken as the true diameter. A measurement of the other important horizontal diameter is impossible, so that the average diameter cannot be determined accurately, but an average of the two diameters which were measured probably approaches the true diameter. A

microphotograph of an example of typical clumps in milk is given in plate 1 A. A clump similar to those selected for measuring the rate of rise is reproduced in plate 1 B. While a number of clumps of all kinds were measured, only the data for those clumps which appeared to be compact and spherical are given in table 6. The large clumps would move across the field so rapidly that no accurate measurement of size could be made while their velocity

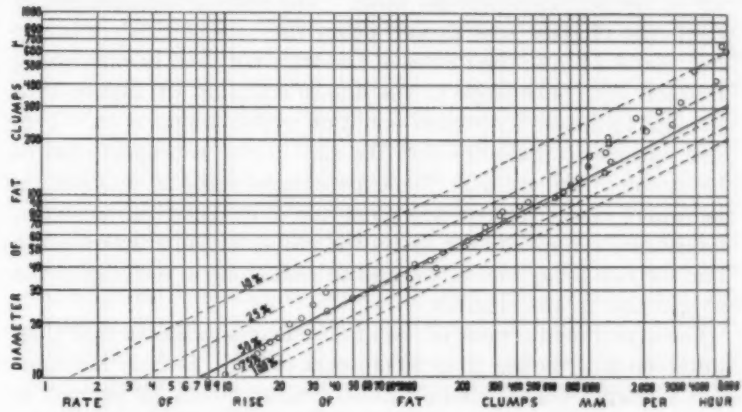

FIG. 2. LOGARITHMIC PLOTTING OF THE RATE OF RISE OF CLUSTERS OF FAT GLOBULES OF VARIOUS SIZES AT 25°C.

The broken lines express the rate of rise as calculated from Stokes equation for clusters of different fat content. The circles represent the experimental values obtained at 25°C. The solid line represents the best line which can be drawn through the experimental points.

was being measured. The fat clusters were then followed by the aid of the mechanical stage, and the measurements of size made as accurately as possible while the fat cluster and mechanical stage were moving in opposite directions. By this method the cluster could be held in view.

The data of table 6 are expressed graphically in figure 2. The broken lines indicate the rate of rise calculated from Stokes' equation for clusters containing various amounts of fat. The

experimental data are represented by the circles, while the solid line is given by the following equation:

$$\log y = 0.552 + (0.519) \log x \qquad (5)$$

It was calculated from the experimental data by the method of least squares for clusters between 13 and 140μ in size. In this equation y indicates the diameter of the cluster in μ and x the rate of rise in millimeters per hour. The walls of the chamber in which the clusters rose slowed down the rate of clusters larger than about 140μ so their rates of rise were not used in calculating equation (5). The slope of the line in equation (5) agrees with the slope indicated by Stokes' equation within 3.8 per cent. This good agreement indicates that the rate of rise is proportional to the square of the radius. The experimental error in determining the rate of rise of clusters was great due to irregularities in shape, to convection currents set up by the movement of clusters other than the one being measured, and to variations in packing of the fat globules in the clusters.

The experimental rates of rise of fat clusters indicates that they contained slightly less than 50 per cent of fat. As only the compact clusters were selected for these measurements, 50 per cent is probably near the upper limit for the fat content of the normal clusters. During these experiments a considerable proportion of clusters were observed which were not compact, and such clusters always rose at a much slower rate. Also many clusters of irregular shape were observed as shown in plate 1 A.

These experiments show that if the fat globules rise as individuals, creaming by the gravity process will not take place in a time short enough to account for normal gravity creaming, but if the fat globules are present in clusters of sufficient size, the normal creaming time is easily explained. This conclusion is in agreement with the previously expressed views of Rahn (28) and van Dam and Sirks (33). That the clusters in milk are of sufficient size to rise rapidly is clearly shown by plate 1 A which is a microphotograph of the clusters in milk which had been pasteurized for thirty minutes at 63°C. (145°F.) and then cooled. This milk had not creamed at the time the sample was taken but it creamed

shortly afterward. This microphotograph shows clearly that milk pasteurized in the holding process at not too high a temperature, if properly cooled and allowed to remain undisturbed will again form clusters very similar to those in properly treated raw milk.

The literature contains the reports of several attempts to correlate the clumping of the fat globules with gravity creaming. Babcock (2) at first, at least, believed that clumping retarded gravity creaming, Palmer, Hening, and Anderson (27) say of some of their experiments: "These results are wholly irreconcilable with those theories which attempt to explain creaming variations by means of fat globule clustering or its absence." On the other hand it is evident that Woll, Babcock and Russell (40) associated the normal creaming of milk with the presence of clusters and its failure to cream as due to the absence of clusters. They did not however, offer any explanation for this behavior or enlarge upon it in any way. Hammer (15) also called attention to the possible variation in the clumps as explaining the variation in the creaming of milk. Rahn (28) van Dam and Sirks (33) Hekma and Sirks (19) Sirks (31) Brouwer (6) Hekma (18) and van der Burg (36) were inclined to believe that clumping of the fat globules was the controlling factor in gravity creaming.

Perhaps some investigators have failed to recognize the important relation between clumping and creaming due to faulty methods used in determining the clumping. A survey of the microphotographs of clumps of fat globules as previously published makes this clear for most of these photographs do not show the real large clusters that are necessary for quick forming deep cream layers but show only what are probably fragments of the large clusters which were originally present. It is only occasionally that the milk can be diluted to any considerable extent without breaking up the large clusters. Occasionally the slighest shearing force will destroy the clusters. In the case of such samples we mounted the unclustered milk in a long trench on a microscopic slide and allowed the clustering to take place in the perpendicular trench; preferably on the stage of a microscope. A magnification of about 100 times seems to be well

suited to the observation of clumps. If too high a magnification were used a portion of a clump would frequently occupy the entire field. A layer of milk about 0.2 to 0.5 mm. deep, 5 mm. wide and 70 mm. long seemed to be suitable for the observation of the clusters.

Our experience indicates that the most successful way to study the relation between clustering and creaming is to set up a microscopic creaming cell at the same time that a bulk sample of the milk is placed in a creaming cylinder. Both microscope and creaming cylinder should be placed at the same temperature and both observed from time to time.

The creaming time elapsing after cooling warm milk can be divided into two parts. First, the time necessary for the fat globules to clump, and second, the time required for the clumps to rise after they have formed. A sharp distinction between these two parts of the creaming time cannot be drawn since the clumps grow in size for some time. The clumping time is greatly influenced by temperature. When milk properly pasteurized by the holding method is cooled rapidly to a low temperature, the clumping usually takes place in from five to thirty minutes. The length of time required for the clumps to rise after they have formed depends largely on their size, shape, and compactness.

In some instances where milk at room temperature was made tenth-normal with sodium hydroxide (10 cc. of normal NaOH to 90 cc. of milk) the clumps took several hours to form but less than an hour to rise. However, when the alkali was added to the milk at a temperature of about 45°C. and was set to cream at 35°C., the clumping and creaming usually occurred within thirty minutes. When the creaming was carried out in a room at 0°C. the cream layer formed was very deep, often occupying 60 per cent or more of the volume. The depth of this layer decreased with time. The clumps were very large, some of them being a centimeter or more in diameter.

Clausnizer (9) observed that if alkali was added to milk (probably cooled) and the milk was set to cream at a cold temperature, creaming did not occur, but if the milk was warmed to a higher temperature a cream layer was obtained.

Some of our observations indicated that when cold milk was made tenth-normal with respect to sodium hydroxide, and was then creamed at 0°C., the cream occupied about 95 per cent of the volume. In fact the cream layer at first was overlooked in some experiments, because it was so near the bottom of the creaming cylinder. Microscopic observations indicated that the fat globules were clumped. After the cream layer had formed at the low temperature it contracted markedly on warming to a temperature of 25°C. or above.

Henseval (20) and Marcas (25) observed that milk which did not cream at low temperatures did cream if the milk was heated to 40° to 60°C. It is possible that the fat was in such a clumped condition that the cream layer occupied almost the entire volume of the milk and was therefore overlooked. Upon warming such milk the customary shrinkage in the depth of the cream layer probably occurred and the resulting cream layer was then recognized.

The clumps formed in milk may vary greatly in size, some clusters may contain only a few globules while others will contain thousands, and under some conditions, are large enough to be seen with the naked eye through the sides of a milk bottle. Clusters vary considerably in their ability to resist being broken up by agitation; the weak clusters will be broken up by a relatively slight jar of the microscope, while the firmest will break down only slowly as the milk is stirred. The clusters are more firm at the lower temperatures. The weakening of the clusters due to an increase in temperature was observed by preparing the microscopic creaming slide in a cold room and then bringing it into a warm room. It was possible, however, to work with some samples of milk at room temperature without very materially weakening the clusters but on the whole very much better clustering was observed and followed at lower temperatures. This is especially true in studying the clusters in the cream layer. The microphotographs were taken in a room with a temperature of about 7°C. (45°F.).

The effect of temperature on clustering was observed in another connection. Babcock (2) made the statement that freshly drawn

milk was not clustered but that it clustered within a few minutes after milking. We have confirmed his observation and have observed in addition that the rate at which it clusters varies markedly with the rate of cooling the milk after it is drawn. On a cold day we could hardly mount the sample before it had clustered although the microscope was set up within 20 feet of the cow being milked. Following the same procedure on a warm day clustering did not take place for two to five minutes after the milk was drawn.

The statement is frequently found in the literature that homogenized milk does not cream and the reason given for this failure to cream is that the fat globules are so broken up that they rise extremely slowly. A series of observations have shown that the fat globules in homogenized milk are not clumped so the absence of clumps accounts for the failure of such milk to cream. It is also common knowledge that the fat globules in homogenized cream are clumped. If milk of average fat content is prepared by adding skim milk to homogenized cream, and this milk is allowed to cream a very deep cream layer is formed and the fat globules are present in the form of very large irregular clusters. This milk will stand vigorous shaking and pasteurization without destroying its creaming ability. This procedure has been used commercially to deepen the cream layer on market milk. Doan (11) in a recent paper has published results which are in agreement with our own experimental observations. He describes a procedure for recognizing the presence of homogenized cream in market milk.

PACKING OF FAT IN GRAVITY CREAM

A second phase of gravity creaming is the way in which the fat globules are packed in the cream layer. Assuming that the same amount of fat has risen into the cream, the extent of packing of the fat globules in the cream layer regulates its depth as well as its percentage of fat.

Van Dam and Sirks (33) concluded that clumping and creaming were controlled by the properties of the milk plasma and were independent of the fat. Palmer and Anderson (26) came to a

similar conclusion in regard to creaming and in addition believed that the viscosity of raw milk could be used as an indication of its creaming ability. They disregarded, however, the effect of the presence or absence of clumps on the viscosity, the effect of which was shown to be of considerable importance by Babcock and his coworkers. Palmer, Hening and Anderson (27) made the important discovery that casein hindered creaming and that the whey colloids promoted both cream rising and satisfactory cream volumes. Hekma (18) found that milk prepared from washed cream and centrifugally separated skim milk creamed better than when gravity separated skim milk was used in its preparation. The relative creaming relation was the same if the washed cream was previously heated at 90°C. for five minutes although the cream layers were not so deep.

The addition of various substances to milk has been shown to increase the creaming and the depth of the cream layer of milk. Clausnizer (9) and Babcock (2) found that adding alkali to milk increased its viscosity and the depth of the cream layer and also caused more rapid and complete creaming. Van Dam and Sirks (33) found that the creaming of a poorly creaming milk was favorably influenced by the addition of the proper amount of alkali.

Hammer (15) added viscogen and found that tremendously deep cream layers were formed, often they extended nearly to the bottom of the creaming cylinder. The pronounced clumping thus obtained was associated with deep cream layers of low fat content.

Rahn (28) showed that the addition of gelatin and gum arabic to milk increased the depth of the cream layer, decreased the percentage of fat in the cream, and caused more exhaustive creaming. Van Dam and Sirks (33) obtained similar results with gum tragacanth, saleb and linseed extract. Babcock (2) added blood serum to milk and found that it caused a clumping of the fat globules. Similar results were also obtained with an artificial emulsion of cotton seed oil. Very important contributions to the creaming of milk have resulted from the investigations carried out at the Hoorn Experiment Station in Holland.

These investigations were directed primarily at an explanation for the fact that the milk from some cows creams well while the milk from other cows does not. Since the milk is elaborated by the mammary gland from materials brought to it by the blood it was conceivable at least that the blood serum from cows whose milk creamed well when added to poor creaming milk would influence the creaming more favorably than the blood serum from cows whose milk creamed poorly. Van Dam, Hekma and Sirks (34) failed to establish such a relation and Brouwer (6) was unable to show any difference in the beneficial effect on creaming of adding the blood serum from steers as compared with cows. He was able to show however, that the beneficial effect was due to the euglobulin fraction of the serum. He demonstrated this in two ways first, by showing that the euglobulin was the only constituent of the blood serum which, when added to milk, produced the marked increase in creaming ability and second, by showing that the blood serum of new born calves exerted no appreciable beneficial effect on creaming and contained no euglobulin. This was taken to indicate also that it was the euglobulin itself which was exerting the effect and not materials carried with it by adsorption. Sirks (31) showed that the electrical charge on the fat globule was very low and its magnitude was not correllated with the clumping.

It is well known that when creaming takes place in a normal manner at low temperature, the fat rises in a few hours or less to give a cream containing about 20 per cent fat, and that after standing the cream layer decreases slowly and the fat content of the cream increases. Any explanation of creaming must account for the marked pause in the packing of the fat globules at a fat concentration of about 20 per cent. The most reasonable explanation is that the clumps pack in the cream with spaces between them containing skim milk. If this explanation is not accepted then some other mechanism must be postulated for keeping the fat globules apart. Evidence against some of these alternate explanations will be presented.

Hunziker (21) wrote, "it is necessary to handle the cream in such a manner as to cause the fat globules to rise to the surface

exhaustively and particularly also to insure the carrying up into, and holding in the cream line the maximum amount of non-fatty constituents."

If the fat globules are surrounded by adsorbed layers of sufficient thickness to limit the fat content of the cream to 20 per cent fat, the thickness of such a layer is easily calculated with approximate accuracy. In making such calculations it is necessary to assume that the fat globules of milk are all of the same size, an assumption which is of course not true but the error introduced is probably very small as will be shown later.

Uniform solid spheres may be packed in space according to three regular systems in which the spheres are in contact with their neighbors. Each system is designated according to the figure in which the sphere may be assumed to be inscribed, the sphere being in contact with a neighboring sphere at the central point of each surface. This figure may be a cube, a hexagonal cylinder, or a dodecagon. In the system of cubical packing the sphere occupies 52.36 per cent of the total volume, in the hexagonal cylindrical packing the sphere occupies 60.4 per cent of the total volume, and in the system of dodecagonal packing the sphere occupies 74.04 per cent of the total volume. In this last named system of packing the spheres occupy the maximum of the total volume which it is possible for uniform spheres to occupy.

If it is assumed that the fat globules are not clumped and are of uniform size, they should pack themselves in cream until each sphere touches its neighbors. If we assume that this packing is according to one of the regular systems described, then we should expect the fat content of the cream to be as high as these calculations indicate unless the fat globules are held apart by some means.

It might be supposed that the adsorbed layer of protein material and water on the surface of the fat globules is of such thickness as to hold the fat globules apart a sufficient distance to account for the low fat content of gravity cream. If this supposition is correct it is possible to calculate the thickness the adsorbed layer would have to be to account for the normal fat content of gravity cream, by means of the following equations, the one to use de-

pending on which condition of packing the fat globules in the cream are assumed to take.

Cubical packing $$x = r\left(\sqrt[3]{\frac{52.36}{V}} - 1\right) \quad (6)$$

Hexagonal cylindrical packing $$x = r\left(\sqrt[3]{\frac{60.4}{V}} - 1\right) \quad (7)$$

Dodecagonal packing $$x = r\left(\sqrt[3]{\frac{74.04}{V}} - 1\right) \quad (8)$$

Where x is the thickness of the adsorbed layer, r is the radius of the fat globule and V is the percentage of the total volume occupied by the fat.

Since cream of 20 per cent fat content is representative of gravity cream the calculations were made on the basis that the fat occupied about 21.8 per cent of the volume of the cream. The thickness of adsorbed layers necessary to account for cream of this fat content and the nearest possible approach of the fat globules to each other is given in table 7, in which an average diameter of 4μ was assumed for the fat globules.

Table 7 indicates that if adsorbed layers are to explain the low fat content in cream they must be abnormally thick. A survey of the literature fails to show that anyone has considered the adsorbed layers to be this thick. If the adsorbed layers are as thick as indicated by table 7 they could be recognized under the microscope for it would be impossible for two fat globules to approach each other nearer than the distances indicated in the table. Microscopic observations indicate that the fat globules are able to approach each other within the resolving power of the microscope, that is, the distance between them is not over 0.2μ. Further evidence that the adsorbed layers cannot be as thick as the calculations in table 7 indicate, was obtained by packing the fat globules as closely as possible by means of a centrifuge.

Since uniform spheres can be made to occupy 74.04 per cent of a total volume, it should be possible to pack fat globules of uniform size so that they occupy this fraction of the total volume

provided they have no adsorbed layers to keep them apart. If the fat cannot be made to occupy this percentage of the total volume the presence of adsorbed layers would be indicated and the data for the maximum fat content actually obtained, as compared with the limiting value of 74.04, would permit the calculation of the thickness of adsorbed layers necessary to account for this difference.

The highest fat content which could be obtained in cream without destroying or distorting the fat globules was determined. The packing was accomplished by means of an electrically driven laboratory centrifuge. A number of preliminary experiments were performed in developing a method that would give consist-

TABLE 7

The systems for the packing of uniform spheres, the percentage of the total volume occupied by the spheres in such systems and the distance between fat globules if packed in 20 per cent cream according to each system

An average diameter of 4μ was assumed for the fat globules

POLYGON CIRCUMSCRIBED ABOUT THE SPHERE	PERCENTAGE OF TOTAL VOLUME OCCUPIED BY THE SPHERE	THICKNESS OF ADSORBED LAYER	DISTANCE BETWEEN FAT GLOBULES
	per cent	μ	μ
Cube	52.35	0.69	1.38
Hexagonal cylinder	60.4	0.80	1.60
Dodecagon	74.04	1.01	2.02

ent results, as each of several factors exerted an influence. Some of these factors were the use of clumped or unclumped cream, percentage of fat present, methods of heating, cooling, aging and concentrating the cream and other details of operation. It was finally found best to use cream of about 20 per cent fat content. In order to make sure that the fat globules would be completely solid and not deformable, it was necessary to age the cream for a time at a temperature near 0°C. It was also necessary to carry out the centrifuging at near 0°C. therefore the centrifuging was carried out in a room held at approximately that temperature.

One of the experiments carried out with raw cream containing clumped fat globules will be described in detail here. Experi-

ments of a similar nature with heated cream and with unclumped raw cream are described in the next section of this paper. Two samples of milk from Holstein cows and two from Guernsey cows were cooled in ice water immediately after milking. They were held at a temperature below 3°C. for twenty hours. Most of the cream was then removed with a small dipper. Each sample was standardized to 20 per cent fat with its respective skim milk. The cream was held at a temperature below 3°C. The cream was centrifuged for thirty minutes. During this time the heat of the electric motor warmed the cream up to about 5°C. The cream was centrifuged in glass tubes which held about 45 cc. The cream layer which was tested for fat was subjected to a force of about 810 times the force of gravity. In testing the cream 2.5 grams were taken from the surface and weighed into a Gerber cream test bottle and the test was then completed.

The fat tests were all made very carefully by the Gerber method. Immediate previous experiments (see Dahlberg, Holm, and Troy (10)) showed that the Gerber test as made agreed within a fraction of a per cent with the Roese-Gottlieb method. If anything the probability is that the Gerber test was a fraction of a percent lower than the Roese-Gottlieb. The data obtained are given in table 8.

Referring to equations (6) (7) and (8) we see that the fat content of the cream is greater than can be accounted for by the various systems of packing except that in which the spheres occupy 74.04 per cent of the total volume. Substituting 64.5 for the V in equation (8) and assuming the fat globules are 4μ in diameter we obtain a value for the thickness of the film of 94 $m\mu$ = 0.094μ. This value does not even approach the true thickness of the film for the cream was very well clumped before centrifuging and since the clumps are broken up with greater difficulty at low temperatures some of these clumps still exerted some effect in preventing maximum packing. That the unclumped fat globules can be packed until the fat occupies 72 per cent of the total volume, which indicates an adsorbed layer of 19 $m\mu$ in thickness will be shown later in this paper.

These experiments indicate that the mechanism which causes

the low fat content of gravity cream, cannot be thick adsorbed layers which hold all globules a definite distance from each other.

The low fat content of the gravity cream cannot be explained by Brownian movement keeping the globules apart. This might be a factor if the fat globules were much smaller but the average fat globule when not near other globules hardly travels further than 1 to 2μ in its sudden movements. These movements cease entirely, due to each globule coming in contact with its neighbors, as the unclumped globules pack in a cream layer, except an occasional small globule which is surrounded by much larger ones so that it has a little free space. If Brownian movement is the factor which keeps the fat globules apart the cream

TABLE 8

Maximum percentage of the total volume occupied by fat obtained by packing raw cream (well clumped fat globules) in a centrifuge at a temperature of 5°C.

SAMPLE NUMBER	BREED	PERCENTAGE OF TOTAL VOLUME OCCUPIED BY THE FAT AFTER AGING THE CREAM	
		1 hour	24 hours
1	Holstein	64	64
2	Holstein	65	65
3	Guernsey	64	64
4	Guernsey	65	65

layer would be deeper the higher the temperature, because Brownian movement increases with a rise in temperature and with a fall in viscosity. It is common knowledge that the depth of the cream layer decreases as the creaming temperature is raised.

Palmer and Anderson (26) found a remarkable relationship between the fat content of the cream, the depth of the cream layer and the viscosity of raw milk. They concluded that the viscosity of the skim milk was an important factor in regulating the depth of the cream layer. Van Dam and Sirks (33) found that the addition of small amounts of lactic acid to milk caused no appreciable change in the viscosity but markedly decreased the creaming. That the clumping of the fat globules and not the

viscosity of the skim milk per se controls the fat content of the cream, can be shown by carefully diluting a sample of well clumped milk with an equal volume of cold water and comparing the volume of cream with that on the undiluted sample. With samples of milk in which the fat was clumped in definite tenacious clumps, the volume of cream obtained by the two methods was found to be essentially the same and the fat in the cream was about equal in both cases. If the cream volume is directly related to the viscosity of the plasma phase the cream volume should have been greatly reduced since the viscosity of the plasma was greatly reduced. The diluted milk was creamed in a cylinder twice the height of the cylinder in which the undiluted raw milk was creamed so that they both contained the same actual amount of whole milk and the cream layers formed were of the same depth. The dilution with water caused a slightly greater loss of fat in the skim milk, although the percentage of fat in the skim milk of the diluted samples was less.

Since the assumption, that an adsorbed layer keeps the fat globules apart in gravity creaming, requires the postulation of absurdly thick layers which could easily be recognized by other methods, and since Brownian movement is not strong enough to keep the fat globules apart and operates in the opposite direction from normal creaming behavior, we are led to adopt the explanation that normal gravity cream is composed of clusters with spaces between the clusters containing plasma with little fat. This explanation was proposed by Rahn (28) and van Dam and Sirks (33).

The calculations based on Stokes' law and the experimental verification of them indicate that the cream rises not as individual fat globules but as clusters. The calculations, made from the curve indicated by the experimental data, for the rate of rise of clusters in which the fat was densely packed indicate that slightly less than 50 per cent of the volume of such clusters was occupied by fat.

In gravity creaming these clusters, each containing about 48 per cent of fat by volume, would probably form cream by grouping themselves somewhat similar to the packing of the spheres,

and thus by superimposing a double system of spherical packing of globules into clusters, and these clusters into cream, the volume of fat in the cream would probably be indicated approximately by applying the 48 per cent packing figures twice, giving about 23 per cent of the volume of the cream as fat, or about 21 per cent by weight. This leads to a value rather close to the fat content of normal gravity cream.

Actual experimental evidence has been obtained with microscopic creaming slides, that this is the method of packing of the fat in the cream. The fat was observed to rise in the form of clusters, and these clusters held their form in the cream and enclosed between them considerable volumes of plasma which contained a few unclumped fat globules. Thus the fat content of the gravity cream was found to be regulated by the clusters. If the clusters were large and irregular, they tended to produce cream of low fat content but large volume for a given amount of fat. If milk heated above 70°C. for thirty minutes was allowed to cream in the microscopic chamber, it was observed that the fat globules rose as individuals, and that they packed themselves closely together in the cream. No large spaces free from fat were observed. Such milk required days to cream in a cylinder and the cream was found to contain a high percentage of fat.

Plate 2 A is a microphotograph through a thin cream layer in the microscopic creaming chamber. This photograph shows clearly how the clumps inclose between them volumes of plasma. Plate 2 B shows the bottom edge of a relatively much thicker cross section of a cream layer. In this photograph the lighting was more intense so that the individual globules do not show but here also the volumes containing little fat can be readily seen as light areas. Also the bottom edge of the cream layer is very irregular. It was not thought worth while to take a photograph of the cream layer obtained from non-clumped fat globules. If the attempt were made to take such a photograph through the cream layer of the unclumped fat to correspond to plate 2 A the picture would be absolutely all black. If a photograph of the bottom edge were taken the result would have been a picture with the upper half absolutely black and the lower half completely

white. In this case the bottom edge of the cream would be a straight line dividing the dark and light portions.

A number of samples of colostrum milk were examined for their creaming ability. The main data obtained will be presented in another paper, but one of the samples showed such striking behavior that it seems of interest to mention it here. This sample of milk contained 0.5 per cent fat, 18.2 per cent total solids, and 13.7 per cent protein. It formed 10.5 per cent of its volume as cream; the cream contained 4.3 per cent fat; and the skim milk contained 0.04 per cent fat, determined by Mojonnier method. The cream line formed on this milk was very definite and clear cut, and could be seen with greater ease than the cream layer on normal milk. This cream would form again in ten to fifteen minutes after gently mixing the sample. The clumps were so large that they could be seen through the walls of an ordinary milk bottle. The viscosity of the whole milk at 25°C. was 6.49 centipoise, and of the skim milk 6.16 centipoise. We have found other samples of colostrum milk which showed marked creaming ability, but we have found no others so far which equalled the sample described here.

Hammer (15) reported that the addition of viscogen to milk in some cases caused the cream to occupy nearly the entire volume of the creaming cylinder. The clumps could be observed with the unaided eye.

Another case of very marked irregular clumps forming a deep cream layer of low fat content is the creaming of milk prepared from skim milk and well clumped homogenized cream. Such milk will frequently give about three-fourths of its volume as cream and the cream may contain as low as 5 to 6 per cent of fat.

Palmer, Hening, and Anderson (27) made the very important discovery that if high fat content cream was added to whey to give about the fat content found in normal milk such whey milk showed good creaming properties. We have confirmed their experiment and have shown in addition that the whey produces clumping of the fat globules. In one of our experiments 50 per cent raw cream was added to rennet whey (which had been previously pasteurized at 60°C. to inactivate the rennet), to make

a 4.5 per cent fat content and the mixture pasteurized. At the end of twenty-four hours a cream volume of 16.3 per cent was obtained. The skim whey contained 0.35 per cent of fat. The fat globules were clumped as shown in plate 3 A. When instead of raw cream, cream which had been heated to 78°C. for fifteen minutes was used in making the whey milk the cream layer occupied 10 per cent of the volume and the skim whey contained 1.9 per cent of fat. In this case the fat globules were also clumped to a considerable extent although the clumping was not so complete nor were the clumps so large as when raw cream was used. The clumps are shown in plate 3 B. Thus the creaming of whey milk is in accord with the clumping of the fat globules.

PASTEURIZED MILK

It is well known that if milk is heated for too long a time or at too high a temperature it creams poorly. Babcock and Russell (3), Farrington and Russell (13), Kersten (22), Hammer and Hauser (16), Kilbourne (23), Hammer (15), Burri (7), Hunziker (21), Harding (17) and Whittaker, Archibald, Shere and Clement (38) have shown that the pasteurization must be done very carefully or the milk will be heated to the extent that the creaming is interfered with. Babcock and Russell (3), Rahn (28) and van Dam and Sirks (33) have shown that severely heated milk contains no clumps of fat globules when the milk is cooled. Babcock and Russell stated that the limit beyond which milk could not be pasteurized without destroying the clumps was between 59° and 65°C.

During the pasteurization of milk by the holding process at normal pasteurization temperature the clumps of fat globules which were originally present in the raw milk are broken up. Milk was taken from a commercial pasteurizer at the end of pasteurization but before cooling. The sample was taken to a room whose temperature was 35°C. and mounted in the microscopic creaming cell. The milk contained no clumps of more than 6 to 8 globules nor did larger clumps form during about eight hours of periodic observation. The great majority of the fat globules were not clumped at all and the small clumps which

were observed are of little importance in creaming. The creaming occurred extremely slowly as would be expected in unclumped milk. Bottles of milk taken from the pasteurizer after pasteurization and before cooling were set to cream at 45°, 35° and 0°C. Only a trace of cream was observed on the samples creamed at 45° and 35° but a normal cream layer was obtained on the sample creamed at 0°C. If, however, the pasteurization temperature is too high the fat globules fail to clump again when the milk is cooled in the customary manner, and the milk fails to give cream in a reasonable time. Thus the detrimental effect of pasteurization on creaming is due to heating the milk to the extent that the fat globules do not clump again on cooling. Some times pasteurized milk is cooled with so much agitation that the clumps which are formed during the cooling are broken up and consequently the milk creams poorly but this is not the fault of the pasteurization since the creaming of raw milk would be injured by similar agitation.

Our experiments have shown that if the pasteurization of the milk and subsequent treatment is such that it gives normal gravity cream the fat globules clump again before creaming occurs. The microphotographs in plates 1, 2 and 3 were all obtained with milk which had been pasteurized.

Roberts (30) Hammer and Hauser (16) Burri (7) van Dam, Hekma and Sirks (34) and Whittaker, Archibald, Shere and Clement (38) have observed that low temperature pasteurization often improves the creaming of milk. This behavior can be explained by our observations that if the milk is agitated, especially at near room temperature or below, the clumps of fat globules are broken down and they do not readily form again even if the milk is then cooled to a low temperature. If, however, after the clumps in raw milk have been broken down at near room temperature, the milk is then carefully pasteurized and cooled rapidly to a low temperature with not too much agitation, the large clumps form again and an improvement in the cream layer is observed over that of the raw milk which has been agitated at room temperature. If the raw milk as soon as it is drawn is immediately cooled rapidly to a low temperature with not too

much agitation it will give a cream layer which will not be materially improved by low temperature pasteurization. The fact that the creaming of the raw milk is improved by pasteurization probably in most cases indicates that the raw milk has been treated in such a way during or after cooling as to break up the clumps of fat globules or to prevent their forming. The cream obtained on such raw milk does not represent the true maximum creaming ability of which it would have been capable as raw milk if properly treated.

It has been suggested by Kirchner (24) Eichloff (12) Hunziker (21) and others that the reason heated milk does not cream is because the albumin is coagulated on the surface of the fat globules and thus weights them so that they do not rise, or rise only slowly. This explanation is not adequate to account for the failure of heated milk to cream as can be shown in various ways. In the first place there is not enough albumin in milk to sufficiently weight the fat globules so as to prevent their rising. If the density of the fat at room temperature is taken as 0.921, of skim milk 1.032, and of albumin 1.275, (Chick and Martin (8) found that the density of dry serum albumin was 1.275) it can be calculated that the layer necessary to weight a fat globule so that it will not rise is 0.134 r, where r is the radius of the fat globule in μ. The layer on a fat globule 4μ in diameter would have to to be 0.268μ thick and the closest such globules could come to each other would be 0.536μ. This would increase the effective volume of the fat globules by about 45 per cent. A milk containing 4 per cent of fat would have to contain 2.52 per cent of albumin to produce the weighting. The amount of heat coagulable protein in milk is usually about 0.2 to 0.3 per cent. These calculations of the thickness of the coagulated adsorbed layer are based on the assumption that it is not hydrated. Since such a layer would undoubtedly be hydrated, its actual thickness, if it formed, would be much greater.

The postulate (Hunziker (21)) that in heated milk a net work structure is formed which prevents the fat globules from rising is not tenable because the viscosity of skim milk which has previously been heated to 70°C. for thirty minutes is less than

the viscosity of the unheated milk as shown by Whitaker, Sherman and Sharp (37). This would not be true if such heating produced a structure which would retard the rising of fat globules for such a structure would also increase the viscosity. This heat treatment of milk markedly reduces the creaming ability of whole milk. The viscosity of whole milk heated under these conditions is also less than the viscosity of the unheated milk.

If coagulation of the protein on the surface of the fat globules produced a layer of sufficient thickness to prevent the rising of cream, the layer could be detected by the packing of solid fat globules by means of the centrifuge. Packing experiments using heated cream were made in a manner similar to those shown in table 8 for raw milk.

TABLE 9

Maximum packing of fat globules in cream which had been heated, and cooled for various periods of time before packing

SAMPLE NUMBER	FAT CONTENT OF CREAM BY PERCENTAGE VOLUME AFTER COOLING FOR		
	2 hours	5 hours	22 hours
1	73.9	71.9	71.9
2	73.9	71.9	71.9
3	75.0*	71.9	71.9

* Centrifuged one hour after cooling.

The cream used was obtained by centrifugal separation from the pasteurized milk of the college herd. The herd contained Holstein, Guernsey, Jersey and Ayrshire cows. The cream was standardized to 20 per cent fat. About 200 cc. was then placed in a 250 cc. Erlenmeyer flask and the flask was placed in a water bath at 72.2°C. (162°F.) for a period of thirty minutes. The cream was stirred constantly by means of a bent glass rod attached to an electric motor. The stirrer revolved fast enough to keep all of the cream in slow motion but not fast enough to whip any air into it. When the heating was completed the flask was placed in ice water and cooled to a temperature below 3°C. Milk of normal fat content made from this heated cream and skim milk

subjected to the same heat treatment fails to cream in a reasonable time. At the end of one hour of cooling the cream was filtered through a layer of cotton about $\frac{3}{4}$ inch in thickness in order to remove any congealed particles resulting from the small amount of fat oiling off during the heating process. Part of the cream was centrifuged two hours after cooling; a second part five hours later, and a third part twenty-two hours later. The centrifuging was for thirty minutes and was done in a cold room as previously described. The data are given in table 9. Each experiment was performed on a different day with a different sample of milk. The higher fat content obtained at the end of one and two hours was probably due to the fat in the globules being still partly liquid so that some of the globules were deformed in the packing process. After five hours, however, a constant lower value was reached. If we assume that the fat globules are all uniform spheres the maximum limit is 74.04 per cent for the volume of the fat, actually 72 per cent was obtained, using 0.961 as the density of the fat at 5°C., that is 2 per cent less than the limit. This experiment indicates that the unclumped fat globules were packed according to the system of maximum packing of spheres. If the thickness of an adsorbed layer necessary to account for this difference of 2 per cent is calculated by Equation (8) we find that for globules of 4μ diameter the layer should be 19 $m\mu$ (0.019μ) thick. That is about one-tenth of the thickness it would have to be, if it were composed of albumin with a density of 1.275, in order to prevent the creaming of heated milk.

Rahn (28) has concluded from measuring the actual rates of rise of individual fat globules from heated and unheated milk that they rise at approximately the same rate.

The difference in the packing in tables 7 and 9 is not due to a difference in the thickness of an adsorbed layer but is due to some of the clumps in table 7 still offering resistance to packing. This was shown by using a different method for breaking up the clumps, namely, by forcing raw cream at a temperature below 3°C. through a capillary several times without introducing air into it. The results obtained are indicated in table 10.

We believe that it is probable that the layer on the fat globules

is less than 19 mμ in both raw and heated milk and also that it is not composed of materials of as high a density as 1.275 otherwise a layer of even the thickness of 19 mμ would cause the fat globules to rise appreciably more slowly than the values obtained in table 3, and it is probable that we would have detected such an effect. Since the experimental rates of rise agree so well with the calculated rate when no correction is made for the weighting effect of the adsorbed layer, it is probable that either the layer is not of

TABLE 10

Maximum packing of solid fat globules by means of a centrifuge in clumped and non-clumped raw cream

The cream was held at near 0°C. for twenty-four hours before being centrifuged.

BREED	TIMES THROUGH THE CAPILLARY	FAT CONTENT OF CREAM BY VOLUME
		per cent
Holstein sample no. 1	0	65.6
	0	64.6
	10	70.3
	10	69.8
Holstein sample no. 2	0	66.7
	0	66.7
	15	70.8
	15	71.9
Jersey sample no. 3	0	67.7
	0	67.7
	15	72.9
	15	71.9

great thickness or it does not have a very high density. The value of 19 mμ is possibly too high as based on the fat test.

SUMMARY AND CONCLUSIONS

1. The rate of rise in milk plasma of individual fat globules varying in size from 1.8 to 41μ in diameter was determined. The experimental results were found to agree very well with the values calculated by Stokes' equation.

2. The fat globules rise so slowly as independent individuals that it would require many times the normal creaming time of milk for them to reach the cream layer.

3. The rate of rise in milk plasma of fat globule clusters varying in size from 10 to 800μ in diameter was determined. The experimental results were found to agree very well with the values calculated by Stokes' equation.

4. The dense spherical clusters probably contain slightly less than 50 per cent of fat by volume.

5. It is shown that clusters rise rapidly enough to account for the normal creaming time.

6. Clusters of sufficient size to account for the normal creaming time of milk were observed in normal raw milk and carefully pasteurized milk.

7. It was found that the clusters arranged themselves in the cream layer with volumes of plasma relatively free from fat between them. The packing of the fat globules into clusters, and then of the clusters in the cream, with volumes free from fat between them, readily explains the low fat content of gravity cream.

The conclusion is drawn, that, for a given percentage of fat, the depth of the cream layer depends primarily on the clustering of the fat globules. Large irregular stable clusters form deep cream layers. Compact approximately spherical clusters, and especially weak clusters, form shallow layers and the fat content of the cream is high.

8. The rigidity of the clusters gradually lessens as the creaming temperature increases permitting closer packing of the clusters at the higher temperatures. This explains why the deeper cream layers are obtained at the lower temperatures. If the creaming temperature is too high the clusters do not form at all or, if formed at a colder temperature, they tend to disintegrate on warming.

9. The stability of the clusters in several instances was found to vary with the sample of milk and its treatment.

10. Mechanical agitation was found to break up the clusters especially at near room temperature.

11. Unclustered fat globules were found to pack themselves

in the cream layer very closely. The fat content of such cream was very high and the cream required days to form.

12. A microscopic creaming cell was described and it was pointed out that in order to compare definitely the creaming of a bulk sample of milk with clustering, it is necessary to carry out the creaming with the microscopic creaming cell under the same conditions as with the bulk sample.

13. It was pointed out that creaming time may be divided into two parts; first, the time required for the clusters to form, and second, the time required for the clusters to rise after they have formed.

14. The thickness of the adsorbed layer on the fat globules of raw milk and milk that had been heated to a temperature which destroyed its clustering and normal creaming power was shown to be the same in as far as this could be determined by the maximum packing of the fat globules by means of a centrifuge.

15. The maximum packing of the fat globules indicated that the adsorbed layer was about 19 mμ in thickness.

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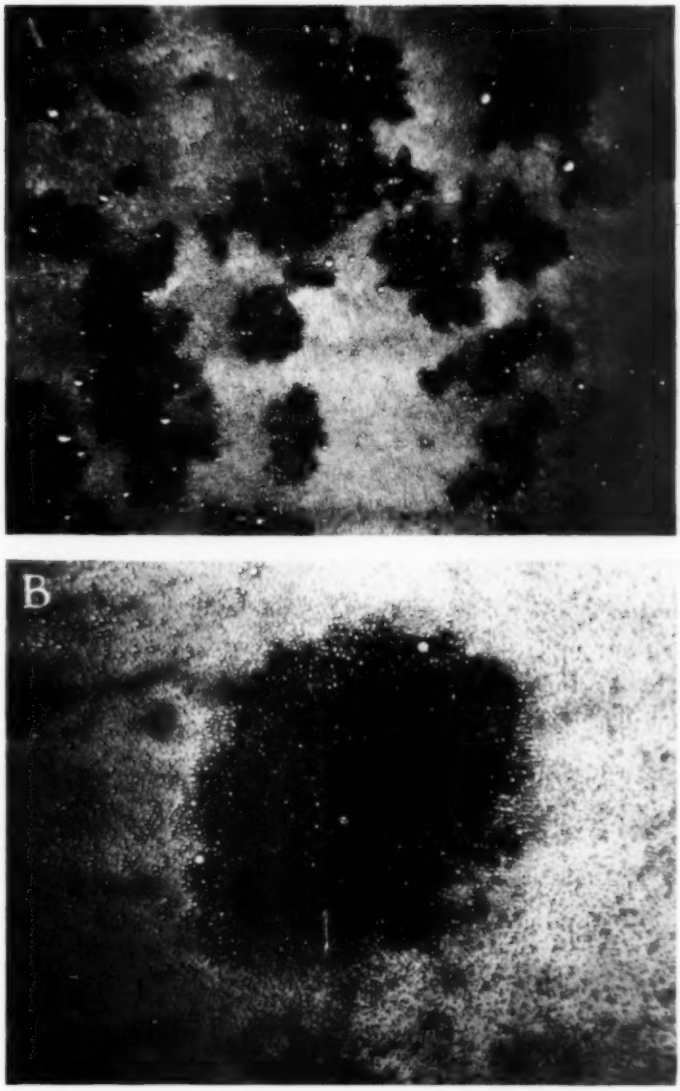
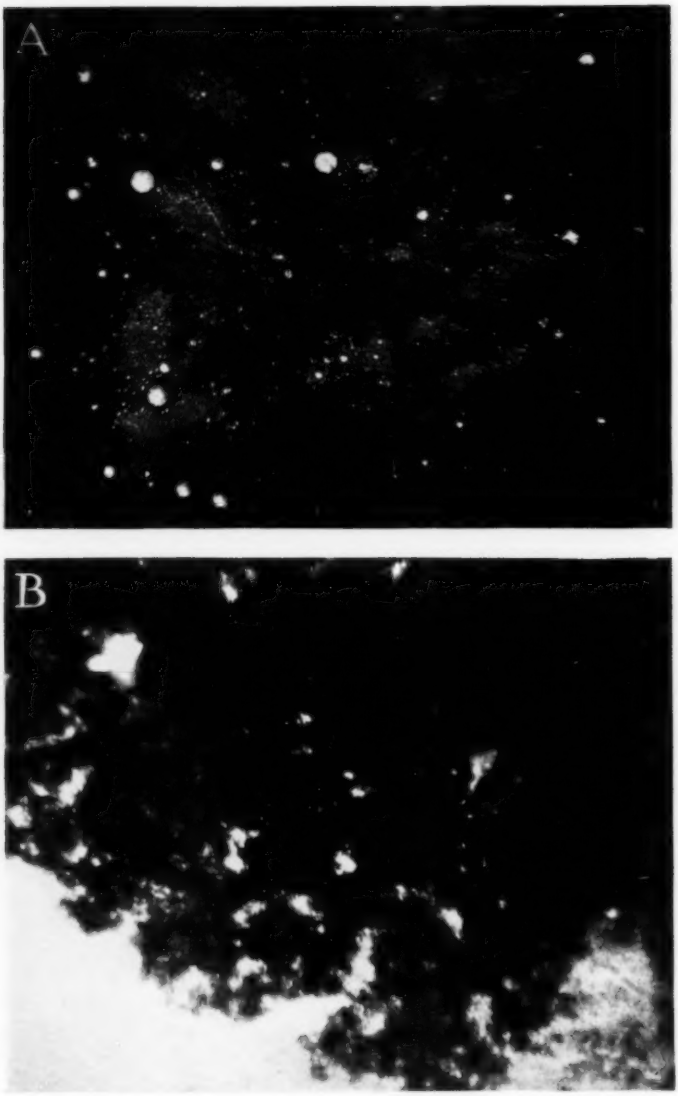
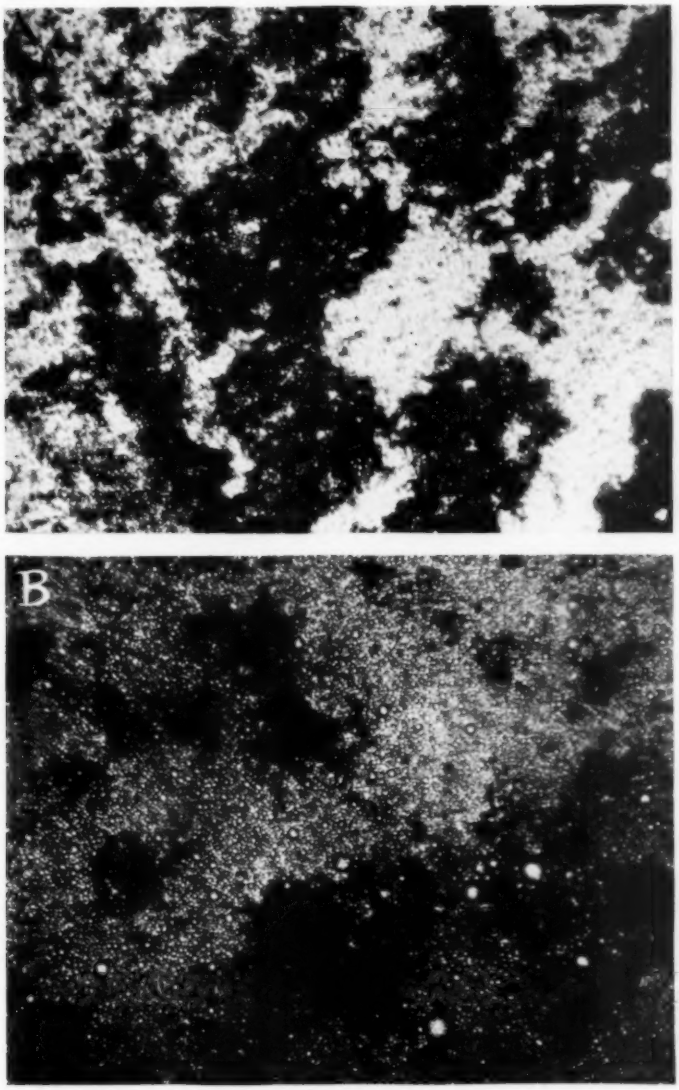


A. Clumps of fat globules in pasteurized milk after cooling.

B. Large nearly spherical dense clump such as was used for measuring the rate of rise.



A. View through a thin layer of cream on cooled pasteurized milk.
B. Bottom edge of a thin layer of cream on cooled pasteurized milk.



A. Clustering of fat globules when raw cream is added to whey and the mixture is pasteurized and cooled. Magnification 141 times.

B. Clustering of fat globules when heated cream is added to whey and the mixture is pasteurized and cooled. Magnification 141 times.

THE ACTIVITY OF THE MAMMARY GLAND

AS DETERMINED BY ANALYSIS OF MAMMARY BLOOD BEFORE AND AFTER MILKING*

E. A. COCKEFAIR

Madison, Wisconsin

There is much difference of opinion among dairymen and students of dairying as to the nature of milk secretion. We would know among other things whether or not milk secretion is a continuous process, proceeding at a uniform rate throughout the period of time between milkings. Does the stimulus of the milker activate secretion or only release the secreted product? Finally is a milk distended udder due mainly to the presence of milk external to the alveolar cells or internal to them? It is our aim in this paper to report the results of work which we believe contribute in a measure to replace theory with fact.

UDDER CAPACITY, INFLUENCE ON CONTINUITY AND RATE OF SECRETION

The commonly accepted idea that milk is largely secreted at the time milk is being drawn was promulgated by many of the earlier observers. Marshall (1) states that the major part of secretion takes place at milking time because a cow's udder cannot contain the entire production at once. Judkins (2) in his college text elaborates the idea. More recent study indicates that this conception should be modified. Gaines (3), Swett (4), Foa (5), and Roehrig (6) report experiments in measurement, perfusion, and pumping back liquids into the udder which prove very definitely that cows' udders do have capacity even greater than their milk yields. Gaines and Sanmann (7) by quantitative analysis of full udders for lactose add new evidence that milk synthesis is complete at the time of milking.

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Upon these observations the above named workers apparently lean to the idea that milk secretion is more or less uniform in rate throughout any twelve-hour period.

Ragsdale, Turner and Brody (9) have reduced to experimental data the principle long made use of by register of merit dairymen that milking more frequently than semi-daily increases both milk yield and butterfat. They place secretion just after milking at 100 per cent and find a 5 per cent reduction rate per hour thereafter due, they think, to pressure of accumulating secreted product.

Just here it may be well to note that in the advancement of these theories it is not always clear what the writers mean by the term "milk secretion." Bayliss (10) in defining secretion in general lists factors which may be included for brevity under two processes: first, synthesis of the normal product within the secreting cell from materials supplied by the blood; second, liberation through the cell walls of the synthesized product. By this definition milk secretion may be thought of first in terms of synthesis and finally liberation of product. Either milk is liberated from the alveolar cells as synthesized, or it is stored in cell vacuoles until the stimulus of milking sets in motion the reflexes which produce rapid release of the product. The latter conception would seem best to account for the phenomena commonly referred to as "holding up" or "giving down" milk.

VARIATION IN COMPOSITION OF MILK AS SECRETED

Jackson and Rothera (11) found milk secreted under different natural conditions to have different electrical conductivity. Davidson (12) found marked changes in milk secreted after the re-injection of sanitarily produced milk into the emptied udder from whence it had just been drawn. Lactose and isotonic salt solutions produced the same results, but distilled water did not. The benefit derived from pumping air into the udder in cases of milk fever may be explained by the production of pressure on the alveoli which stops secretion and thereby cuts off the drain of sugar from the blood. Careful dairymen know that high producing cows should not be milked out completely during the first

flush of lactation. These observations all suggest an uneven rate in milk secretion.

Swett (4) has recently published results on milking excised udders. Yields from such milkings on three cows were approximately 50, 69, and 85 per cent of normal. Turner and Uren at Missouri and Olson, South Dakota, from unpublished data kindly submitted to the author furnished evidence that corroborates in the main Swett's findings. One way to interpret these results is that milk is synthesized and liberated into the lumina, milk ducts, and cisterns to the extent of from 50 to 85 per cent of normal yield at the time of milking. Another interpretation would assume that milk is held in a synthesized state in the alveolar cells, except for a slow leakage of low fat milk known as first milk; and that excised udders are sufficiently responsive to the milking stimulus to liberate their stores to a point when, perhaps through lack of blood circulation, there is insufficient water to perfuse the remaining fraction through the cell walls.

BLOOD PRECURSORS OF MILK

In 1906 Kaufman and Magne (13) found sufficient difference in the glucose content of mammary blood and jugular blood to account for the lactose found in milk. On this suggestion Meigs, Blatherwick and Cary (8) found a similar difference in blood phosphatides and inorganic phosphorus to account for milk fat. Cary (14) followed these discoveries with a determination of amino acids in mammary and jugular blood. His results accounted for milk proteins. Hence the precursors of the three principal organic constituents of milk are accounted for.

Since it has been possible for the above named workers to obtain indicative results on milk secretion by blood analysis it occurred to us that analyses of mammary blood before and after milking might throw light on the problem of rate of secretion.

Accordingly we planned to take samples of blood from the mammary veins of lactating cows just before milking. A check sample of jugular blood was also taken immediately after the mammary sample. After milking, another mammary sample of

blood was taken from the same vein as before milking. We used Meigs method of taking sample; namely, by means of inserting a large hypodermic needle into the vein and removing approxi-

TABLE 1

Inorganic phosphorus of mammary and systemic blood in lactating cows (averages)

Milligram per 100 cc. plasma

NAME OF COW	BEFORE MILKING	AFTER MILKING	SYSTEMIC	SEMI-DAILY MILK YIELD
				pounds
Pauline	5.82	5.57	5.29	5–8
Lady	5.61	6.06	6.25	5–8
Aloise	4.95	4.37	4.96	8–2
Liza	5.76	5.39	5.45	7–9
Jones:				
Blood	5.52	5.25	5.12	22–26
Plasma	5.56	5.03	5.11	
Susan:				
Blood	5.27	5.04	5.02	11–13
Plasma	5.42	4.84	5.35	

TABLE 2

Organic phosphorus of mammary and systemic blood in lactating cows (averages)

Milligram per 100 cc. plasma

NAME OF COW	BEFORE MILKING	AFTER MILKING	SYSTEMIC	SEMI-DAILY MILK YIELD
				pounds
Pauline	6.74	6.61	6.62	5–8
Lady	7.72	7.49	7.32	5–8
Aloise	7.72	7.17	7.43	8–2
Liza:				
Blood	7.53	7.30	7.34	7–9
Plasma	5.56	4.76	5.66	
Jones:				
Blood	7.20	6.49	7.06	22–26
Plasma	5.84	5.26	5.93	
Susan:				
Blood	8.57	8.08	8.33	11–13
Plasma	7.63	7.40	7.32	

mately 100 cc. of blood which was kept from clotting by means of 1 cc. saturated solution of sodium citrate. This blood was used to determine inorganic and organic phosphorus.

Six cows were used in this experiment. Two were Holstein, one Ayrshire, and three Guernsey. They represented low, medium and high production. From ten to twenty blood samples were taken from each cow and analyzed for the two forms of phosphorus. Each sample analysed was done in four parts for accuracy. The Briggs Modification (15) of the Bell Doisy

TABLE 3

Daily variations in blood phosphorus

Milligram per 100 cc. whole blood

DATE (1927)	INORGANIC PHOSPHORUS			LIPOID PHOSPHORUS		
	Before milking	After milking	Systemic	Before milking	After milking	Systemic
May 31	5.18	4.98	4.73	7.54	6.39	7.22
June 1	4.46	3.59	3.28	9.69	9.27	8.70
June 2	3.41	3.34	2.99	10.03	9.43	9.64
June 3	4.50	4.18	4.27	10.33	9.61	10.04
June 4	4.48	4.16	4.32	9.85	8.89	9.36

TABLE 4

Periodic variation in blood phosphorus after milking

Milligram per 100 cc. whole blood

TIME	INORGANIC PHOSPHORUS			LIPOID PHOSPHORUS		
	Before milking	After milking	Systemic	Before milking	After milking	Systemic
4 p.m.	4.32	3.50	3.50	10.48	10.11	10.40
6 p.m.		3.66			10.70	
8 p.m.		4.04			10.54	
10 p.m.		4.79			10.24	
12 m.		4.46			10.54	10.65

method was used for inorganic phosphorus determination, and Bloor's (16) method for the determination of lipoid phosphorus. The results show only slight differences, as might be expected, but the preponderence of difference is in favor of the idea that mammary blood before milking is higher than systemic blood in both inorganic and lipoid phosphorus. In after milking mammary blood both forms of phosphorus, in approximately the

same degree, are lower than in systemic blood. Tables 1 and 2 give the total average of each cow.

These results were secured from blood taken at variable intervals of time. Although the ratio between before milking and after milking mammary blood and systemic blood was fairly constant, the quantity of both inorganic and lipoid phosphorus from time to time was variable. To determine if this variability was normal or due to some other cause a single cow (Susan) was made a subject for five consecutive days. The results (table 3) show, so far as one trial can be relied upon, that the phosphorus content of blood is subject to daily variations. It would seem from these figures and from previous analyses that lipoid phosphorus tends to be high when inorganic phosphorus is low and vice versa.

A similar morning and evening test also shows a small range of variation as shown by the following analysis:

	INORGANIC PHOSPHORUS			LIPOID PHOSPHORUS		
	Before	After	Systemic	Before	After	Systemic
a.m.	4.73	4.62	3.47	9.44	8.64	9.63
p.m.	4.89	4.55	4.09	10.60	9.84	9.84

Meigs and co-workers found a difference in blood phosphorus content when the blood was taken during the milking act as compared to samples taken when cows were undisturbed. In order to compare the effect of massage on blood phosphorus content as compared with conditions before and after milking, we took samples as usual but just after taking the before milking and systemic samples the udder was thoroughly massaged and another sample taken before milking was begun. Results are given in order of samples taken as follows:

	INORGANIC PHOSPHORUS	LIPOID PHOSPHORUS
Before milking	5.58	10.58
Systemic	4.63	10.80
Massage	4.76	9.87
After milking	4.32	10.62

Massaging would seem to have some influence in stimulating some form of udder activity which calls for the use or retention of both forms of phosphorus.

If milk secretion proceeds at a diminishing rate as indicated by the production curves of Ragsdale, Turner and Brody it might be possible to trace this diminishing rate through blood analysis. For this test a high producing cow was chosen (Jones). After taking the before, systemic and after milking samples as usual another sample was taken from the mammary vein every two hours thereafter until eight hours had elapsed. The results are presented in table 4.

DISCUSSION

The phosphatides (lecithin for example) approximate in molecular composition one part by weight of phosphorus to eighteen parts of fat. In the synthesis of milk fats from phosphatides it is generally accepted that the phosphorus radical is replaced by a fatty acid radical. In the synthesis of 4 per cent milk four parts of fat per hundred are produced, one-eighteenth of which in the lecithin form or 0.224 part was phosphorus. One hundred parts of 4 per cent milk contain in composition 0.086 part of phosphorus (17). If we divide the amount of phosphorus released from lecithin in the production of 100 parts of 4 per cent milk by the amount of phosphorus contained in that milk in its normal composition we have the figure 2.6. Therefore approximately one and one-half times as much phosphorus is released in fat synthesis as is utilized in milk composition. The return of this phosphorus to the blood is ascribed by Meigs to be the cause of higher inorganic phosphorus in mammary blood than in systemic blood.

If milk secretion proceeds at a uniform rate the ratio of phosphorus in mammary blood to that of systemic blood should be fairly constant, high in inorganic phosphorus and low in lipoid phosphorus as Meigs found it. If milk secretion is at a standstill just before milking the phosphorus content of mammary blood should be high. The lipoid phosphorus should be high because it is not drawn upon; the inorganic phosphorus should

be high as Meigs suggests because of reabsorption. Our data would seem to indicate this. After milking when the alveolar cells are empty we should expect rapid absorption of milk precursors from the mammary blood. Lipoid phosphorus should therefore be lower and our analyses seem so to indicate; inorganic phosphorus should be higher but our results indicate that it is lower. If we consider, however, that depleted cells are apt to be very active cells, and a strong osmotic current must be flowing to them from the blood, then it is probable that the inorganic surplus would be retained in the alveolar cells until osmotic equilibrium should be sufficiently established to set up a counter current.

We offer the above data as incomplete evidence tending to support the idea that the rate of milk secretion is not uniform. Much more data are needed on the effect of massaging and on the variation of blood composition at intervals during a twenty-four hour period. Analyses of mammary blood before and after milking should include other precursors such as amino acids and blood sugar. The effect of pressure on milk secretion needs further investigation.

CONCLUSION

With few exceptions our data show that mammary blood just before milking is higher both in inorganic and organic phosphorus than systemic blood. Just after milking both forms of phosphorus are lower in mammary blood. We interpret these results to mean that just before milking synthesis of milk is practically nil, which allows the blood to retain its load of lipoids. At the same time inorganic phosphorus liberated during the hours of active secretion is being absorbed by the blood.

Just after milking both forms of phosphorus in the mammary blood are reduced. The lipoids are being used for milk fat synthesis and the inorganic phosphorus liberated by the process is not at once reabsorbed by the blood because the main osmotic current is toward the alveolar cells. During milking or four to six hours later lipoids are being utilized. After four to six hours the inorganic phosphorus in the mammary blood increases

probably because the osmotic interchange is sufficiently equalized to allow its return.

From evidence found in the literature supported by our observations and analyses, we believe that milk secretion is most active just after milking and that it proceeds in diminishing rate as the pressure and presence of accumulating synthesized milk interferes with cellular activity. The pressure of a well filled udder is probably due for the most part to intra-cellular milk vacuoles rather than from surcharged cisterns, ducts and lumina. The liberation of this vacuole milk by the stimulus of milking doubtless gave rise to the old idea that milk is secreted mainly during the milking process.

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THE DETERMINATION OF MOISTURE IN DRY SKIM MILK BY THE BIDWELL-STERLING TOLUENE-DISTILLATION METHOD*

P. A. WRIGHT

Research Laboratories, Bureau of Dairy Industry, United States Department of Agriculture

A comparison of the results obtained from a number of moisture determinations on dry skim milk by the use of the vacuum oven and the Bidwell-Sterling (1) toluene-distillation methods shows that in all cases the percentages were greater when the latter method was used.

Dry skim milk contains on the average 48.74 per cent of lactose. If this component is assumed to be in the form of the monohydrate, the combined water is equivalent to 5 per cent of the weight of the lactose or 2.44 per cent of that of the product.

According to Gillis (2) lactose loses its water of crystallization when placed under reduced pressure and in the presence of a dehydrating agent at 70°C. for ten to fifteen hours. The author found, however, that a sample of pure lactose monohydrate heated in a vacuum oven maintained at 27 inches vacuum and at a temperature of 100°C. was still losing weight at the end of thirty-four hours.

Jones and McLachlan (3) determined the moisture in lactose hydrate by the toluene-distillation method and recovered approximately the theoretical amount after five hours' distillation. Ninety per cent of the amount was recovered after two and one-half hours' distillation. The author has confirmed these results.

A comparison of the two methods when used to determine the moisture content of two dry milks is given in figure 1, wherein are plotted the results of determinations made for various time intervals.

These results, as well as those obtained when longer time

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TABLE 1

Showing results obtained by the vacuum oven and the Bidwell-Sterling toluene distillation methods

TYPE OF DRY SKIM MILK	VACUUM OVEN METHOD*	BIDWELL-STERLING METHOD†	DIFFERENCE
	per cent	*per cent*	*per cent*
Spray	2.57	2.80	+0.23
	3.22	3.48	+0.26
	3.86	4.25	+0.39
	2.49	2.74	+0.25
	2.82	3.12	+0.30
Flake	2.94	3.13	+0.19
Drum dried	3.91	3.96	+0.05

* Sample maintained at 100° C. and 27 inches vacuum for two and one-half hours.

† Distillation continued for one and one-half hours.

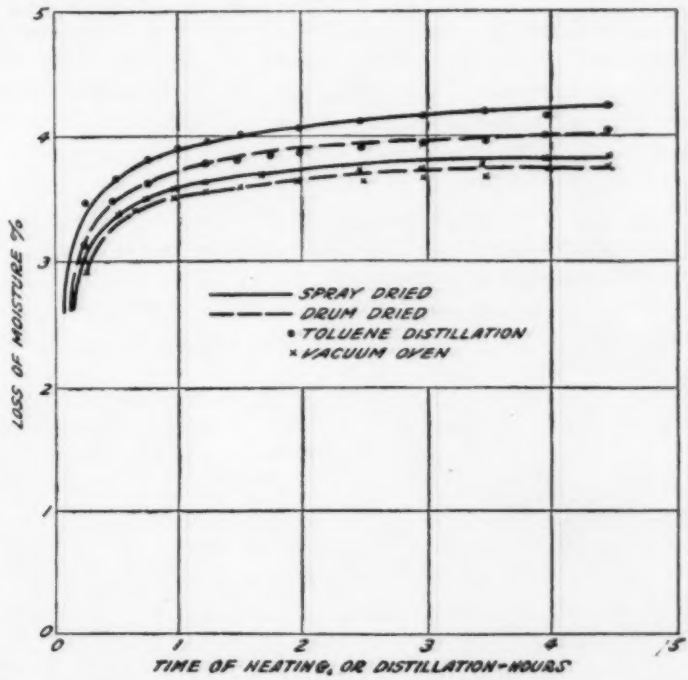

FIG. 1. SHOWING THE RATE OF LOSS OF MOISTURE OBTAINED BY THE VACUUM OVEN AND THE BIDWELL-STERLING TOLUENE-DISTILLATION METHODS

intervals were used, indicate a progressive and continuous loss of weight, thereby indicating some decomposition. This decomposition is also indicated by the yellowish color of the dry skim milk residue which with prolonged boiling becomes a brownish shade. The decomposition of lactose occurred readily in the presence of disodium phosphate.

These experiments and a number of others upon lactose and upon dry milks, indicate that of the two methods the Bidwell-Sterling toluene-distillation method furnishes the more reliable results. Because of the progressive continuous loss of weight (fig. 1) some arbitrary distillation time must be chosen. Two hours seems to furnish satisfactory results.

In addition to the greater reliability in results the Bidwell-Sterling method is more suited to commercial conditions. Vacuum pump and oven equipment are unnecessary, and since 50-gram samples are used a comparatively inexpensive balance may replace the fine chemical balance.

SUMMARY

Comparisons are made between the vacuum-oven method and the Bidwell-Sterling toluene-distillation method for the determination of moisture in dry skim milk.

The use of the toluene-distillation method, modified to use a 50-gram charge and a two-hour distillation time, is recommended.

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THE HEAT STABILITY AND FEATHERING OF SWEET CREAM, AS AFFECTED BY DIFFERENT HOMOGENIZATION PRESSURES AND DIFFERENT TEMPERATURES OF FOREWARMING*

BYRON H. WEBB AND GEORGE E. HOLM

From the Research Laboratories, Bureau of Dairy Industry, United States Department of Agriculture

In the preparation of sweet cream for market purposes, the prevailing practice is to homogenize the product at 1000 to 1500 pounds per square inch after pasteurization at approximately 64° to 74°C. The lowest possible homogenization pressures that will prevent the separation of the fat globules under marketing conditions are used, since it is assumed that increases in the pressure greatly affect the heat stability and are therefore apt to promote "feathering."

It is has been noted repeatedly in work in these laboratories that the stability of a milk of high butterfat content to heat varies greatly with the temperature of forewarming and that the forewarming temperature producing maximum stability is not the temperature generally used for pasteurization.

The changes in stability to heat which were found to occur in sweet cream under varying conditions of homogenization and temperatures of forewarming, and their relation to "feathering" and to the preparation of sterile cream are considered in this paper.

EXPERIMENTAL

Basic relationships

The relationships which exist between the temperatures and duration of heating of cream before homogenization at various pressures, the percentage of butterfat in the cream, and the time of coagulation of the product have been determined.

* Received for publication February 18, 1928.

TABLE 1

Relationship of time of coagulation to butter fat content, homogenization pressure and preheating temperature of milks and creams

BUTTERFAT CONTENT	HOMOGENIZATION PRESSURE	TIME OF COAGULATION AT 120°C.				
		Check, not heated, not homogenized	Preheating temperature			
			60°C.	70°C.	80°C.	90°C.
per cent	*pounds per square inch*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
0	1,000	150	151	148	145	146
3	2,500	124	100	95	107	119
4	2,500	98	80	84	98	102
	500	132	131	129	131	134
	750	132	131	129	131	134
5	1,000	110	85	82	85	93
	2,000	137	101	114	122	120
	2,500	137	104	116	126	117
	3,000	137	97	118	129	115
6	2,500	134	63	70	104	107
8	2,500	98	67	77	90	83
	1,000	107	81	72	100	
	1,000	120	82	79	95	110
10	2,000	107	60		100	
	2,500	120	66	82	100	83
	3,000	107	60		97	
	3,500	120	66	87	100	82
13	1,000	120	60	70	90	90
	500	120	74	95	113	100
	750	120	50	62	112	105
	1,000	133	7	12	85	60
	1,000	123	20	80	117	120
	1,000	115	5	34	86	63
	1,500	110	2	10	75	62
20	2,000	115	1	37	70	30
	2,000	110	0		70	
	2,500	115 (?)	−0	25	58	45
	2,500	115	1	40	60	17
	3,000	115 (?)	−0	35	58	40
	3,500	115 (?)	0	40	59	28
	3,500	115	2	48	46	0

TABLE 1—*Concluded*

BUTTERFAT CONTENT	HOMOGENIZATION PRESSURE	TIME OF COAGULATION AT 120°C.				
		Check, not heated, not homogenized	Preheating temperature			
			60°C.	70°C.	80°C.	90°C.
per cent	*pounds per square inch*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
30	500	140 (?)	2	65	85	74
	500	137	−0	10	97	71
	750	140 (?)	0	42	85	0
	1,000	140 (?)	0	0	1	1
	1,000	137	−0	1	72	61
	2,000	137	−0	−0	−0	−0

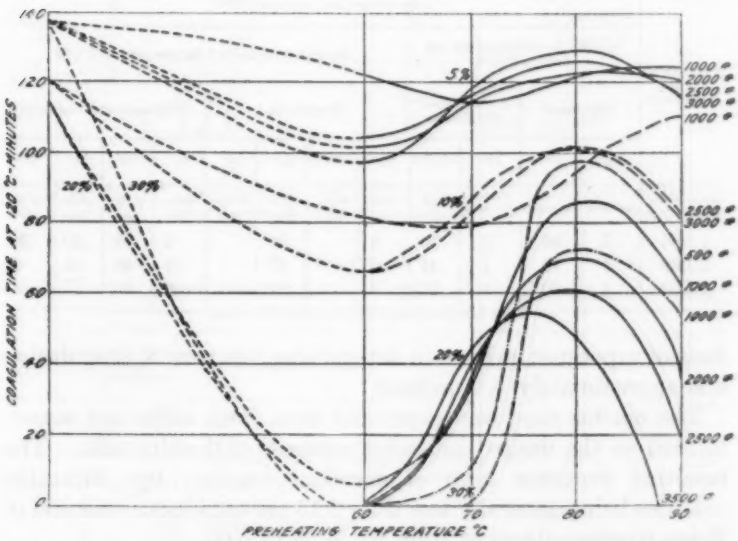

FIG. 1. RELATIONSHIPS OF BUTTERFAT CONTENT, HOMOGENIZATION PRESSURE AND TEMPERATURE OF PREHEATING TO THE HEAT STABILITY OF MILKS AND CREAMS

The method of procedure was as follows: The cream was first heated to the required temperature after which, in most cases, it was immediately homogenized and the coagulation time determined by sterilization at 120°C. In this paper the term "preheating temperature" is used to designate that temperature to which the cream was heated without holding, before sterilization. The homogenizer used was a 90-gallon, Progress type. To find the coagulation time, samples were sterilized in tins at 120°C. until the first signs of coagulation were noticed. The

TABLE 2

Showing the effect of the duration of heating upon the heat stability of cream containing 20 per cent butterfat

HOMOGENIZATION PRESSURE	TIME OF COAGULATION AT 120°C.											
	Sample A—acidity 0.145 per cent, pH 6.68				Sample B—acidity 0.165 per cent, pH 6.63							
	Preheated		Forewarmed 10 minutes		Preheated				Pasteurized 30 minutes			
	60°	80°	60°	80°	62°	70°	80°	90°	62°	70°	80°	90°
pounds per square inch	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
1,000	5	86	3	70	8		61		4	58	60	35
2,000	1	70	1	44	−0		47		−0	40	25	0
2,500	1	60	1	38	0		49		−0	44	17	−0

limit of experimental error in determining this time of coagulation was approximately ± 1 minute.

The creams used were separated from fresh milks and standardized to the desired butterfat contents with skim milk. The resulting products were of excellent quality, the titratable acidities being generally less than 0.15 per cent lactic acid and of H-ion concentrations of from pH 6.70 to 6.60.

The results in table 1 show the relationship between butterfat content, homogenization pressure, and preheating temperature to the heat stability of milks and creams.

In figure 1 are plotted a few of these results.

In the manufacture of evaporated milk the time of forewarming

of the milk is of some importance and an increase in this factor, to a certain limit, increases the heat stability of the final product.

The effect of holding cream of 20 per cent butterfat content at the preheating temperatures before homogenization is given in table 2.

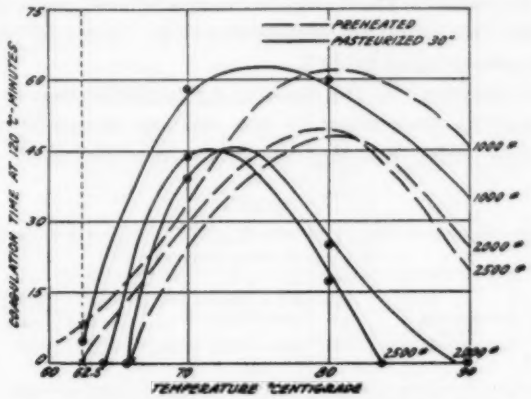

FIG. 2. EFFECT OF DURATION OF HEATING UPON HEAT STABILITY OF CREAM CONTAINING 20 PER CENT BUTTERFAT

TABLE 3

Showing the coagulation time in minutes at 120°C. of creams varying in the order of preheating and homogenization

BUTTERFAT CONTENT	HOMOGENIZATION PRESSURE	HEAT TREATMENT	CHECK	60°	70°	80°	90°
per cent	*pounds per square inch*		*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
20	1,000	Preheated before homogenization	125	20	80	117	120
		Preheated after homogenization at 60°	125	32	32	30	21

These data indicate that the figures obtained upon preheated cream (table 1, fig. 1) also hold true for pasteurized cream with the modification that as the time of holding increases the maximum of the stability curve shifts from 80°C. toward 70°C., the extent depending upon the duration of the heating period and

slightly upon the homogenization pressure. This is well illustrated in figure 2 which is plotted from the data in tables 1 and 2.

Homogenization prior to preheating and at different temperatures

Results of experiments wherein homogenization at 60°C. is carried out prior to preheating show clearly that preheating must be carried out prior to homogenization. Some of the results obtained are given in table 3.

Homogenization at the preheating temperatures or at 60°C. subsequent to preheating to the various temperatures yields values that differ but slightly from those obtained when the

TABLE 4

Showing the coagulation time in minutes at 120°C. of creams homogenized at 60°C. or at the preheating temperatures

BUTTERFAT CONTENT	HOMOGENIZATION PRESSURE	PREHEATED, NOT COOLED BEFORE HOMOGENIZATION			PREHEATED BUT COOLED TO 60° BEFORE HOMOGENIZATION	
		60°	80°	90°	80°	90°
per cent	*pounds per square inch*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
10	1,000	82	95	110	97	95
	2,500	66	100	83	95	81
	3,000	66	100	82	95	79

homogenization is carried out at the various preheating temperatures subsequent to the heating (table 4).

Viscosity and heat stability

A strikingly consistent relationship was found to exist between the heat stability and the viscosity of the product. The viscosities were determined by an Ostwald capillary pipette and are expressed as relative viscosities (water = 1). The results are shown in table 5.

These data are plotted in figure 3 which shows the reciprocal relationship existing between the viscosity and the heat stability.

Feathering of cream

The formation of a flocculent coagulum, known as feathering, when sweet cream is added to hot coffee, is a problem of con-

TABLE 5

Showing the relative viscosity and time of coagulation of various creams preheated and homogenized at various temperatures and pressures, respectively

HOMOGENIZATION PRESSURE	TEMPERATURE OF PREHEATING	5 PER CENT BUTTER FAT		10 PER CENT BUTTERFAT		20 PER CENT BUTTERFAT		30 PER CENT BUTTERFAT	
		Time of coagulation at 120°C.	Relative viscosity*	Time of coagulation at 120°C.	Relative viscosity*	Time of coagulation at 120°C.	Relative viscosity*	Time of coagulation at 120°C.	Relative viscosity*
pounds per square inch	*°C.*	*minutes*		*minutes*		*minutes*		*minutes*	
1,000	60	122	1.35	82	1.81	5	1.75	−0	4.18
	70	114	1.31	79	1.70	34	1.58	1	4.91
	80	121	1.47	95	1.72	86	1.49	72	2.24
	90	124	1.50	110	1.78	63	1.58	61	3.30
2,000	60	101	1.45			1	3.50	−0	Very viscous
	70	114	1.47			37	1.84	−0	13.80
	80	122	1.47			70	1.58	−0	5.34
	90	120	1.52			30	2.02	−0	Very viscous
2,500	60	104	1.38	66	2.18	1	4.05		
	70	116	1.37	82	1.88	40	1.75		
	80	126	1.48	100	1.76	60	1.58		
	90	117	1.50	83	1.88	17	3.16		
3,000†	60	97	1.49	36	2.17	2	3.65		
	70	118	1.45	87	1.91	48	1.75		
	80	129	1.47	100	1.65	46	1.66		
	90	115	1.52	82	1.89	0	Very viscous		

* Water = 1.

† 3500 pounds used for the 20 per cent cream.

siderable commercial importance. Burgwald (1) points out that the acidity of the product is an important factor in the feathering phenomenon.

In view of the fact that acidity is probably the controlling factor in feathering, it was deemed advisable to ascertain the true hydrogen-ion concentration as well as the titratable acidity of the samples. Accordingly the hydrogen-ion concentration

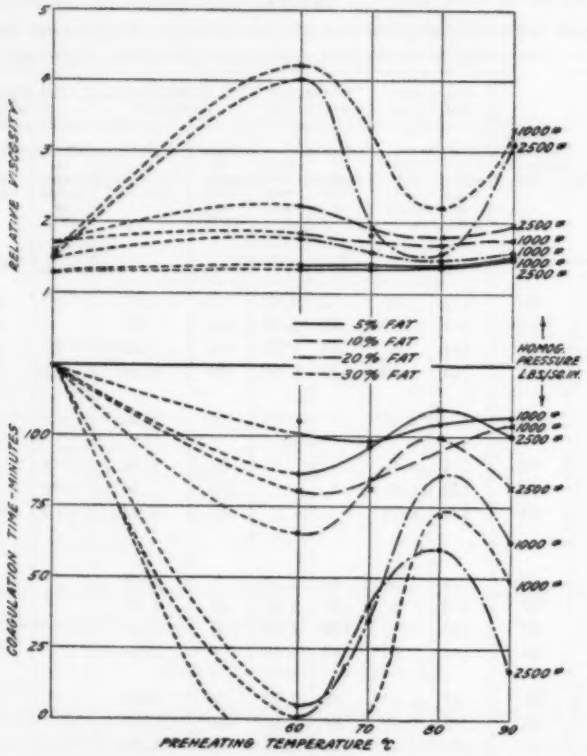

FIG. 3. SHOWING THE RECIPROCAL NATURE OF CHANGES IN HEAT STABILITY AND RELATIVE VISCOSITY

was determined by the quinhydrone electrode (2) on numerous samples of 20 per cent cream. The results of these determinations, plotted against the titratable acidity and expressed in terms of lactic acid, are shown in figure 4. The curve obtained

by Sharp and McInerney (3) for fresh milk is reproduced on the same figure.

Feathering tests were carried out in three different ways:

1. Addition of water (93° to 97°C.) to cream
2. Addition of coffee (93° to 97°C.) to cream
3. Addition of cream to coffee (86° to 90°C.)

Feathering in coffee occurs at a much lower acidity than feathering in water, due probably to the presence of tannin and

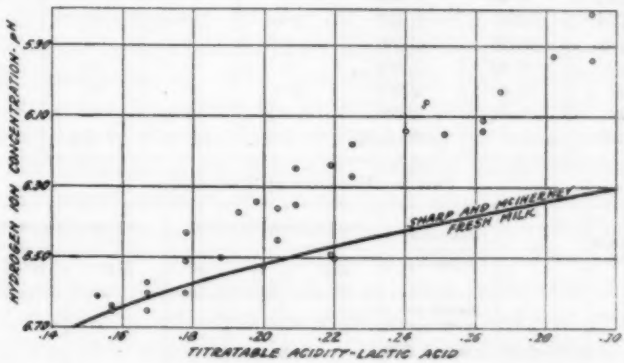

FIG. 4. RELATIONSHIP BETWEEN TITRATABLE ACIDITY AND pH OF CREAM CONTAINING 20 PER CENT BUTTERFAT

salts in the coffee which promote coagulation. As pointed out by Burgwald (1) cream will feather at a lower acidity when coffee is added to it, than when cream is added to coffee.

The results obtained on cream feathering are shown in table 6. The results in part 1 of this table are for preheated cream, and the feathering tests were conducted in water. The data in the second part of table 6 are for cream pasteurized thirty minutes, and feathering tests were here conducted in coffee. Two extremes are thus represented. The cream used to obtain the data in part 1, being subjected to conditions less severe than that of part 2, shows a higher acidity necessary before feathering

TABLE 6

Showing the degree of feathering of cream that contains 20 per cent butterfat and that is subjected to various heating temperatures before homogenization

Part 1. Preheated cream

TITRATABLE ACIDITY	pH	HOMOGENIZATION PRESSURE	FEATHERING IN WATER (93° TO 97°C.) AT RESPECTIVE PREHEATING TEMPERATURES			
			60°	70°	80°	90°
per cent		*pounds per square inch*				
0.156		2,500	+		−	
0.167	6.57	2,500	+		−	
0.193	6.37	1,000–3,000	+++		−	
0.204	6.45	1,000	+	−	−	−
0.204	6.45	2,500	++	−	−	−
0.209	6.25	2,500	+++	+	−	
0.22	6.49	1,000	+	−	−	−
0.22	6.49	2,500	++	−	−	−
0.24	6.14	2,000	+++	+++	−	+
0.292		1,000–2,500	+++	+++	+++	+++

Part 2. Pasteurized 30 minutes

TITRATABLE ACIDITY	pH	HOMOGENIZATION PRESSURE	CREAM ADDED TO COFFEE			COFFEE ADDED TO CREAM		
			62.5°	70°	80°	62.5°	70°	80°
per cent		*pounds per square inch*						
0.15 or less	6.65–6.75	1,000–2,500	−	−	−	−	−	−
0.167	6.65	1,000	−	−	+++	+++	++	+++
0.167	6.65	2,000	++	+	+++	+++	++	+++
0.188		1,500		−	++		+++	
0.188		2,500		++	+++		+++	+++
0.22	6.25	1,000–1,500	Feathering certain	++		Feathering certain	+++	
0.22	6.25	2,000		+++			+++	
0.246	6.14	1,500		+			+++	
0.246	6.14	2,000		+	−		+++	+
0.246	6.14	2,500		+			+++	

−, no feathering; +, trace of feathering; ++, feathering; +++, heavy feathering.

develops. The treatment given the cream used to obtain the results shown in part 2 corresponds to ordinary commercial practice.

A study of part 1 of table 6 shows that the tendency of cream to feather follows closely the tendency of cream to coagulate upon sterilization according to the figures in table 1. The data in figure 1 may therefore be considered as representing the relative tendency of cream to feather under the various conditions of preheating, homogenization pressure, and butterfat percentages given.

The results given in table 2 indicate that when cream is pasteurized instead of preheated the point of maximum stability shifts from 80°C. toward 70°C. It would appear, therefore, that cream to be homogenized for market purposes should be pasteurized at approximately 70° to 74° for thirty minutes. This conclusion is further borne out by the fact that (table 6, part 2) cream pasteurized at 70°C. was generally less susceptible to feathering than those samples pasteurized at 62.5° or 80°C.

Knowledge of the acidity of the cream to be homogenized is the best criterion of the amount of pressure which the product will withstand without feathering. An acidity of 0.165 per cent would appear to mark the danger point above which homogenized cream very probably will feather. A titratable acidity of 0.165 per cent will generally allow a cream containing 20 per cent butter fat to be pasteurized at 70° to 74°C. and homogenized at 1000 to 1500 pounds pressure without disastrous effects. It must further be remembered that the temperature of the coffee used in the test greatly affects feathering. A coagulation will occur in coffee at boiling temperature much more readily than in coffee cool enough to drink.

DISCUSSION

It is evident that at every pressure of homogenization and for any percentage of butterfat, as high as 30 per cent, the maximum heat stability is attained by preheating the cream to 80°C., excepting for those of low fat content and at low homogenization pressures when 90°C. slightly increases the stability. At 60°C., the lowest temperature at which it is practical to homogenize, the minimum heat stability of all creams is reached except for those of very low butterfat content for which the heat stability curve sometimes reaches its lowest point at 70°C.

Pasteurization of 20-per-cent cream for thirty minutes causes the maximum of the heat stability curve to shift from 80°C. toward 70°C.

Feathering, being a process of heat coagulation, follows the heat stability curve, and consequently pasteurization of coffee cream is most advantageously carried out at 70° to 74°C. (158° to 165°F.). This practice is, at present, widely used among commercial plants as a safeguard against bacterial action. It now appears also to be the best temperature to use to prevent feathering.

The temperature of pasteurization and the homogenization pressures are, however, minor factors to be considered when compared with the quality of the cream. In no case during this work was cream which contained 20 per cent butterfat and which was preheated at any temperature from 60° to 90° and homogenized at any pressure up to 3000 pounds found to feather if the cream used was strictly fresh and of low acidity. Occasionally, however, creams, abnormal in some respects, may feather, even though they be of apparent excellent quality.

The problem of feathering is, then, mainly a problem of quality of product. Favorable heat treatment and homogenization pressure may aid in preventing feathering in a poor lot of cream but the sure way to overcome the difficulty is the use of only the highest grade of cream with a titratable acidity below 0.15 per cent.

The quality of a cream in this respect may be judged by acidity or H-ion concentration determinations. Either test is sufficient for determining approximately the heat treatment and homogenization pressure which a cream will withstand.

Because of variations in chemical or physical properties in different creams no definite limits can be expressed for the acidity danger line, with respect to feathering. The data given, therefore, should be interpreted as setting forth the principles governing feathering and not the solution of this problem for each case.

The interesting fact that such a wide difference exists in the heat stability of sweet cream when either the butterfat percentage, heating temperature, or homogenization pressure is varied, presents an extensive field for speculation as to the probable chemical and physical changes which take place in the product.

The reciprocal relationship existing between the heat stability curve and the viscosity curve for a given cream, as shown in figure 2, may be significant. The cause of increased viscosity in homogenized cream is generally considered to be due to a clumping of the fat globules.

Doan (4) has been able to distinguish viscolized milk by the characteristic clumps of its fat globules due to viscolization.

It is well known that a change in the salt equilibrium and the formation of acid during heating may greatly affect heat coagulation. It is possible, therefore, only to suggest at this time that the degree of clumping is a result of variation in potential of the fat globules and that this is an important factor in the heat stability of homogenized creams.

Considerable attention has been given in this work to the preheating of cream as contrasted with its pasteurization or forewarming for a specified time. This has been done because of the value of such results when applied to a process for the manufacture of sterile cream as developed in these laboratories (5).

A study of figure 1 has shown that for maximum stability sweet cream containing 20 per cent butterfat and of good quality should be preheated to 80°C. before its homogenization instead of to the lower temperatures customarily used. The subsequent sterilization makes previous pasteurization or forewarming unnecessary.

The troublesome heat coagulation encountered in the sterilization of homogenized cream can accordingly be eliminated by preheating the product to 80°C. before homogenization. The fact must be recognized, however, that any homogenized cream, to withstand ten to fifteen minutes sterilization, must originally be of low acidity and good quality. The curves in figure 1 for cream containing 20 per cent butterfat show the relative margin of safety which exists between the various homogenization pressures when an 80°C. preheating temperature is used. Average cream of over 0.15 per cent titratable acidity would probably coagulate in less than half the time which was found for the product used here.

SUMMARY

1. The heat stability of cream, measured in terms of time of coagulation at 120°C. as affected by butterfat content, temperature of heating before homogenization, and homogenization pressure has been determined. A definite relationship was found in their influence on heat stability.

2. An increase of homogenization pressure lowered the time of coagulation. Maximum stability resulting from preheating occurred when 80°C. was used, and minimum stability during sterilization occurred when 60°C. was used. An increase in butterfat content invariably lowered the heat stability of homogenized cream.

3. The same general relationship exists in pasteurized as in preheated cream, with the exception that the point of maximum heat stability shifts from 80°C. in preheated creams to approximately 70° to 74°C. in pasteurized creams.

4. Where pasteurization was practiced prevention of feathering was partially successful by the treatment producing maximum heat stability, namely pasteurization for thirty minutes at 70° to 74°C.

5. The basic criterion for predicting whether or not a cream will feather is quality. Acidity and H-ion concentration were used for quality determinations. Pure, fresh cream of 20 per cent butterfat content and of 0.15 per cent acidity can generally be pasteurized from 65° to 85°C. and homogenized at any pressure up to 3000 pounds without danger of feathering. With optimum treatment 0.165 per cent acidity is the danger line for feathering.

6. An increase of viscosity of preheated homogenized cream is accompanied by a decrease in heat stability. It is suggested that variation of potential upon the fat globules may be an important factor in determining the heat stability of the product.

7. In the preparation of sterile cream for market purposes maximum stability during sterilization was obtained by preheating to approximately 80°C. before homogenization.

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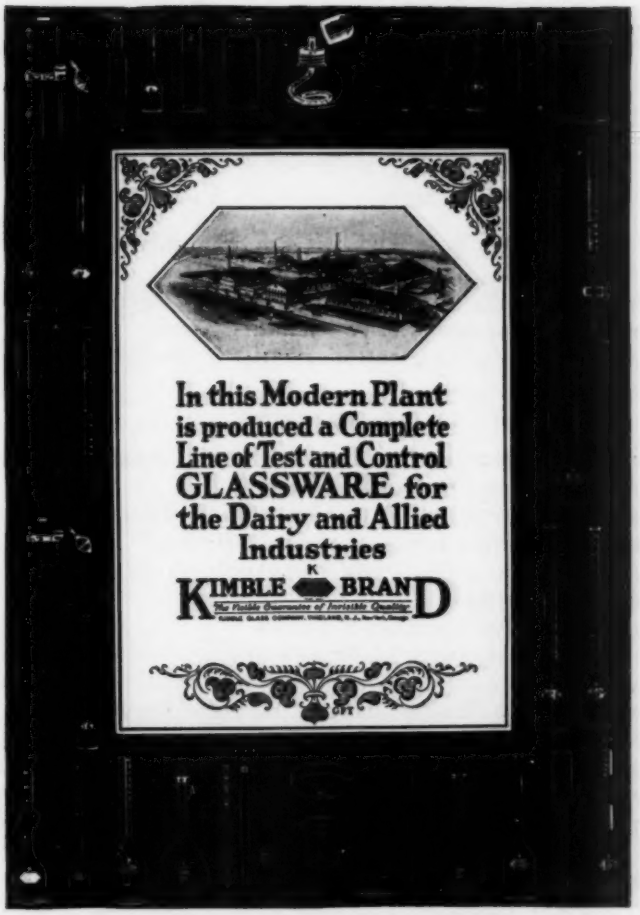

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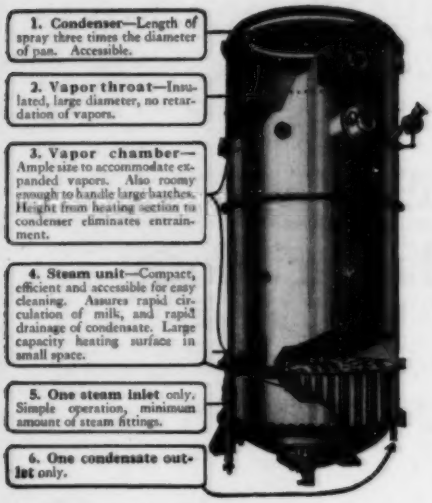
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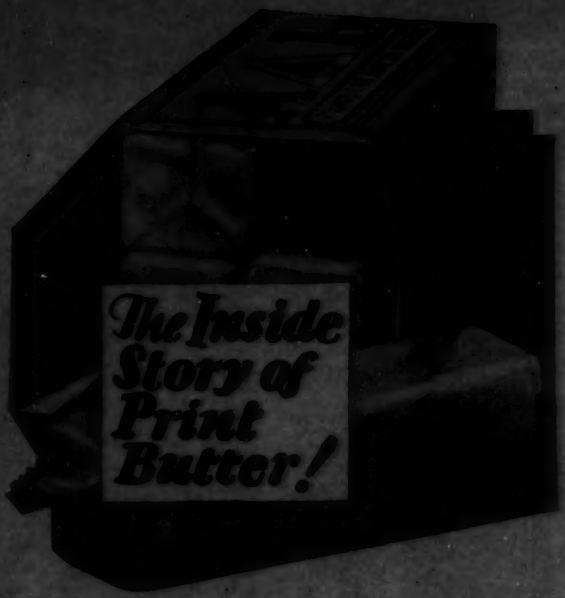

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